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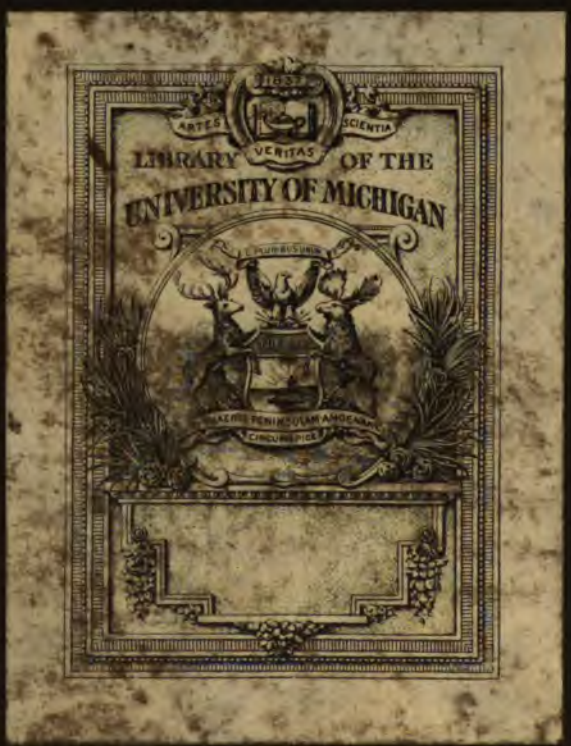
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Shetland Isles
Orkney Islands
ATLANTIC OCEAN
GERMAN OCEAN
NORTH SEA
IRISH SEA
ENGLISH CHANNEL
FRANCE
Longitude West of Greenwich
Alluvium
Drag & Eocene
Chalk
Wealden
Oolite
Lias
Trias
Coal Measure
Millstone Grit
Carbonif. Limestone
Old Red Devonian
Upper Silurian
Lower Silurian
Laurentian
Granite
Basalt

2625.

MANUAL OF GEOLOGY

Theoretical and Practical

BY

JOHN PHILLIPS, LL.D., F.R.S.
SOMETIME READER IN GEOLOGY IN THE UNIVERSITY OF OXFORD

EDITED BY

ROBERT ETHERIDGE, F.R.S.
AND
HARRY GOVIER SEELEY, F.R.S.

IN TWO PARTS

PART II.

STRATIGRAPHICAL GEOLOGY AND PALÆONTOLOGY

By ROBERT ETHERIDGE, F.R.S.
ASSISTANT-KEEPER, GEOLOGICAL DEPARTMENT, BRITISH MUSEUM
LATE PALÆONTOLOGIST TO THE GEOLOGICAL SURVEY OF GREAT BRITAIN

With Map, Numerous Tables, and Plates

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PREFACE.

DURING the period which has elapsed since the publication of the last edition of Professor Phillips' Manual, no departments of science, probably, have advanced so rapidly, or with so much scientific acumen, as Geology and its handmaid, Palæontology —two branches of knowledge so closely interwoven that the one can only be understood through the other; the history of the Sedimentary Rocks and their stratigraphical relations being determined by the Succession of Life in time and its Distribution in space. So extensively, indeed, has the science of Geology grown —in its widest and fullest sense—that no one mind can hope to grasp in their entirety the great truths and facts that have, during the last fifty years, enriched its literature in every quarter of the globe.

In 1854, Professor John Morris published the Second Edition of his Catalogue of British Fossils, then numbering 1280 genera and 4000 species. Since that date 3000 genera and nearly 12,000 new species have been described, thus bringing up the muster-roll of extinct life, in the British islands alone, to 3680 genera and 16,000 known and described species.

So great an addition to the literature of palæontological Geology called for the extension and revision of Professor Phillips' Manual, a work which, at the time of its publication, was the only one that dealt almost exclusively with the succession of the stratified rocks and their associated life-contents. As far as possible, the original *plan* of Phillips has been adhered to; but of the *text* itself, few pages of the edition of 1855 now remain.

One hundred and sixteen tables of organic remains have been prepared, and brought down to 1884, embracing the accumulated wealth of the labours of past and present investigators during the last thirty years. Eleven of these tables contain every known British genus, zoologically or systematically placed, and with the number of species in each, showing their broad distribution through time. The remaining 105 tables are devoted

entirely to the analysis, relation, historical value, and distribution of specific life through each group of strata. These have been specially prepared for the use of students.

I have only to add, with my esteemed colleague in his preface to Vol. I., that "the changes necessary to bring the science of the last generation into harmony with current knowledge and thought, have been more serious than were anticipated when the revision began." This volume has been entirely re-written, and differs in construction and detail from any known manual; it is hoped that every page will repay the student, if read with care and patience. The Palæontological analyses through the general text, as well as the tabular deductions, are for the first time fully prepared for English students.

Very considerable additions have been made to the original Illustrations, which were prepared under the direction of Prof. Phillips himself. These will be found interspersed through the Plates, with descriptive letterpress. Many of the characteristic species named throughout the text may be referred to in the Quarterly Journal of the Geological Society and the richly illustrated volumes published by the Palæontographical Society, the authors of the numerous monographs in which have earned enduring gratitude through the magnificent memoirs which have appeared on the Fossil Corals, Mollusca, Polyzoa, Crustacea, Reptilia, Echinodermata, Plantæ, &c.; the volumes devoted to the Brachiopoda alone, by Mr. T. Davidson, F.R.S., being a lasting monument of unprecedented labour and learning.

R. ETHERIDGE.

14 CARLYLE SQUARE, S.W.,
August, 1885.

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A MANUAL OF GEOLOGY,

THEORETICAL AND PRACTICAL.

PART II.—*PALÆONTOLOGY.*

INTRODUCTION.

THE known portion of the earth, which is exhibited in the great masses of existing land, is composed of successive accumulations of water-formed strata, sometimes more or less altered into a crystalline or igneous condition, and frequently associated with igneous rocks. This arrangement, which is usually hidden from our view by the surface soil, is represented upon a geological map by a series of colours. Each of those colours indicates a geological formation which marks or signifies a division of geological time.[1] We there learn the sequence of the beds, and their relation to each other. The direction in which they extend is shown; the varying breadth of country which they cover gives some idea of the extent of their original deposition; the irregularities of outcrop exemplify the kind of denudation which they have experienced; and frequently great dislocations abruptly terminate the present known limits of the deposits.

But although a geological map conveys all this information (and much more) to the student, he soon finds, when his knowledge of the several beds becomes practical, and he tries to follow each stratum through the country, that his note-book becomes filled with data (more valuable to himself than those of any map-records) of the structure and subdivisions of the beds, and of the changes in mineral character which indicate to him differences in their modes of accumulation. He collects their fossils, and thus learns the distribution of life over portions of the ancient sea-bed in which the stratum was formed, and realises in this way something of the connection between the deposit he is examining and the strata that occur above and below.

[1] Consult the great series of geological maps (on the scale of 1 inch to the mile) constructed by the Geological Survey; also the Geological Map of England by Sir A. C. Ramsay; Greenough's Map of England, geologically coloured, and published under the auspices of the Geological Society; Professor A. Geikie's Geological Map of Scotland; and the Geological Map of Ireland, by J. B. Jukes.

Such a history the student may aspire to work out for himself with the help of aids such as this Manual offers. In the early days of geological observation, however, sections were recorded in one district without regard to the beds in other localities, and fossils have been described or accumulated in different public museums, so that the materials have only gradually been brought together, out of which it has been attempted to write the ancient history of the rocks that compose the "crust" of the British Islands.

It may be convenient here to state that we shall endeavour, where the data permit, to give, in the first place, a short introduction which will present some idea of the stratum as a whole; then to describe its physical characteristics; the divisions into which it may be separated; the typical areas in which it may be studied; and lastly, the history of its fossil life as it is successively brought before us. And in thus arranging the matter, it is believed that the student will appreciate the results which are arrived at by a careful comparison of the life of the successive beds one with the other, as an aid in estimating the value of the physical differences between them, no less than as offering a record of the first appearance, the successive migration, or the extinction of the various groups of animals and plants which have appeared in the British areas during the past geological epochs.

CHAPTER I.

STRATIGRAPHICAL OR HISTORICAL GEOLOGY—THE HISTORY OF THE FORMATION OF THE EARTH'S CRUST.

THE history of the formation of the recognisable crust of the globe, can only be learnt or arrived at by piecing together what we know of its different parts, each portion having been previously and separately investigated. This history may be read in two ways—either by investigating or tracing backwards from the *present* to the *past*, or by narrating occurrences as nearly as possible in the order in which they took place. Comparatively few parts of the earth's surface have up to the present time had their intimate structure examined or even sketched out, although probably the oldest or Palæozoic portions have received the most careful attention. Many of the events, therefore, which are believed to have occurred *contemporaneously* in different areas, may in reality have taken place in succession, and have been separated by great spaces of time, the records of which we have not yet discovered, and which probably may never be found.

The structure of the British Islands is better understood than that of any other part of the globe, and presents in the space occupied the most complete series of rocks of any known area. It may, therefore, be taken as the type of the Historical Succession of the Stratified Rocks and their associated life, through time, so far as we are enabled to penetrate back into the great past. Where other regions possess a

group of rocks which, in the British Islands or the Celtic province, have no existence or "homotaxial" representative, such a group necessarily would be best described from its known locality. The greater part of the oldest and most widely-distributed of the *Archæan* rocks occurs on the North-American Continent. For the complete elucidation of their history, we still await the researches of American geologists; and if their past labour and progress afford or indicate a measure of future efforts, grand indeed will be the result.

Divisions of Geological Time.—In describing the great groups of stratified rocks or formations, it must be understood that their names are commonly used to designate the successive periods of time in which they were formed.

For convenience, all geological time has been divided (and naturally so) into three great groups, or the succession of periods known as *Primary*, *Secondary*, and *Tertiary*. Equivalent but more classic terms, based upon life distribution, are *Palæozoic*, *Mesozoic*, and *Cainozoic*, signifying respectively ancient life, middle or less ancient life, and recent or modern life. These names were proposed by Professor John Phillips, and are now generally adopted. They essentially refer to the presence and distribution of organic life through time.

Primary Period.—The Primary period refers simply to that which preceded the Secondary, being the most ancient or first great cycle of time of which we at present know anything, but by no means the first or beginning of all time; of that *we know nothing*. There is no definite starting-point in the so-called Primary or Palæozoic period; our chronological commencement is lost in the remote past.

Secondary Period.—The Secondary period naturally succeeds the Primary. In this great division of time, however, we have a recognised base and close, a beginning and ending; both boundary lines being definitely governed by life, as well as by recognised stratigraphical or physical changes, producing unconformity and discordant strikes.

Tertiary Period.—The Tertiary period, in like manner, has its special characteristics; no species that had occurred in the Secondary era, lived on or passed into the Tertiary sea. In other words, no Secondary form passed through these changes which mark, and ceased with, the close of the Cretaceous period, and commencement of the Tertiary epoch.

Geological time, as before stated, is thus arranged: We may either commence our researches downwards through these three great life-divisions, or we may begin from the unknown base—the Azoic or Archæan time of Dana, the pre-Cambrian, Cambrian, and Silurian eras of other physicists—and read upwards through the recognised successive changes that have taken place during the long history of these Palæozoic, Mesozoic, and Cainozoic epochs.

Neozoic Time.—It was suggested by the late Professor Edward Forbes, both upon palæontological, physical, and petrological grounds, that it might be advantageous to obliterate the division between the Secondary and Tertiary periods, thus dividing geological time into two great epochs instead of three, viz., *Palæozoic* and *Neozoic* (Old

and the New), on the grounds that there was really no difference between the Mesozoic and Cainozoic, and therefore, that it would be more philosophical to divide the whole lapse of time into two great epochs, and probably, as our knowledge and researches become more complete, this may be carried out.

Up to the present time, however, all research tends to the retention of the present nomenclature; the great *Middle* or Mesozoic period being very distinctively characterised by its own special fauna in all classes of the animal kingdom.

The most marked feature of the *Tertiary period* is the continuity of its generic fauna, many forms that lived in the Eocene seas of Britain and Europe being still in existence.

Stratigraphical Subdivisions based upon the Progress of Life.—We may from the groupings and distribution of organic remains, adopt subdivisions of geological time based upon the progress of life, under whatever aspect of its condition or development may be preferred. This mode of grouping is convenient, and on zoological or biological principles is true. The great amount of research and attention given to the study of geology and palæontology during the past thirty years has resulted in the following arrangement, by which the great series of stratified rocks are placed in seven divisions or ages. These divisions are adopted by Dana in his Manual of Geology.[1] They include all the sedimentary strata, from the earliest known Cambrian to the Quaternary or modern period.

The Seven Ages.

I. **Archæan Time.**—The beginning, comprising a vast epoch of time, probably at first without life, in which, however, finally appeared the earliest (so far as we know) and simplest forms of life, plants (?) and animals.

II. **Cambrian and Silurian Age,** or Age of Invertebrates.—All known forms of animal life during this period were distinctively INVERTEBRATE, embracing the *Hydrozoa*, *Actinozoa*, *Crustacea*, *Mollusca*, &c.

III. **Devonian, or Age of Fishes.**—In addition to the Invertebrata, the group of fishes (the lowest among the Vertebrata) appeared and predominated; a few forms presented themselves at the close of the Silurian period. The Devonian age of America may be divided into two eras, an earlier (Oriskany and Corniferous), and a later (Hamilton, Chemung, and Catskill).

IV. **Carboniferous Age**—Age of Amphibians and Acrogens.—Chiefly characterised by a flora composed mainly of acrogens which then had their greatest development, as shown by our coal fields. The Coniferæ began in the Carboniferous, and had their greatest expansion in the Reptilian age. The Carboniferous Reptilia belonged to the order Amphibia, and Crossopterygian, Acanthodian, and Placodormal (Elasmobranch) fishes predominated.

V. **The Age of Reptiles** ranges from the Permian to the end

[1] "Manual of Geology," p. 139.

of the Cretaceous epoch, a vast period. The dominant vertebrata were Reptilia, with many genera of Teleostian Fishes.

VI. **Tertiary Age, or Age of Mammals.**[1]—The Tertiary age is characterised by the presence of Mammalia in nearly all its subdivisions. The Pliocene period is individualised by the remains of cetacean mammalia, many of which may have been derived from the older Miocene series. The more recent deposits (post-Pliocene) contain a large number of genera belonging to the Pachydermata, Carnivora, Rodentia, and Ruminantia. Mammals began (so far as we know) in the Reptilian age, and the *Marsupialia* were the highest race of this Sixth age.

VII. **Quaternary, or Age of Man—**

Subdivisions of Geological time :—

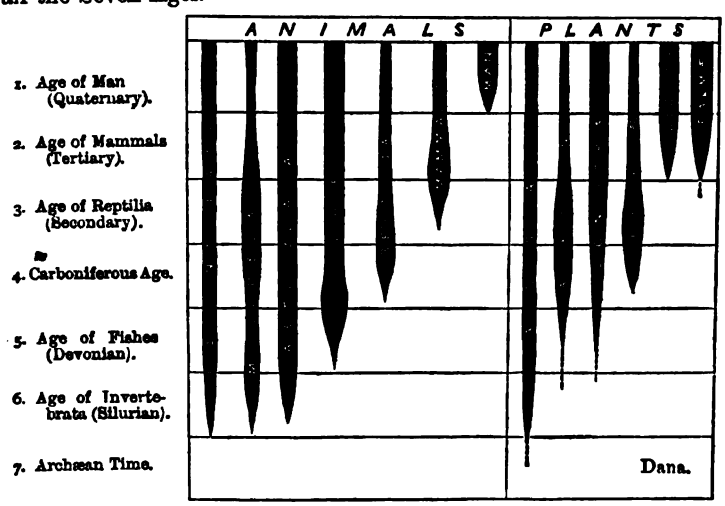
I. ARCHÆAN TIME, including an Azoic and an Eozoic era, though *not yet* distinguished in the rocks—
   1. Azoic Age.
   2. Eozoic Age.

II. PALÆOZOIC TIME—
   1. The Age of Invertebrates, or Silurian.
   2. The Age of Fishes, or Devonian.
   3. The Age of Coal-plants, or Carboniferous.

III. MESOZOIC TIME—
   The Age of Reptiles.

IV. CAINOZOIC TIME—
   1. The Tertiary, or Age of Mammals.
   2. The Quaternary, or Age of Man. (*Dana.*)

The annexed diagram broadly illustrates the progress of life through all the Seven Ages.



[1] See Gaudry, "Les Enchainements du Monde Animal dans les temps Géologiques-Mammifères Tertiaires." Paris, 1878.

The horizontal bands represent the ages in sequence; the vertical series show the great groups or divisions of the animal and vegetable kingdoms, and their ranges through the successive ages. The lower end of each life-group marks the point in geological time when the type it represents began. The varying width in the column indicates the increment or decrement (increase or decrease) of the groups in time, according to our present knowledge of the distribution of fossil remains, annulosa and annuloida *animals*.

THE CŒLENTERATA[1] commenced early in the Silurian period, and with but little variation in force have never ceased to exist.

THE MOLLUSCA through the *Brachiopoda*, *Pelecypoda*, *Gasteropoda*, and *Cephalopoda*, preceded the *Cœlenterata*, and continued to increase until the close of the Secondary or Reptilian age, when as a group they greatly preponderated and reached their maximum. The *Cephalopoda* have played a very important part through all time, especially during the Silurian, Jurassic, and Cretaceous ages.

THE ARTHROPODA OR ARTICULATA commenced in the lower Cambrian as *Crustacea* (*Trilobita*, *Phyllopoda*) and *Annelida*, and have gone on increasing or expanding in genera and species up to the present time.

FISHES first appeared at the close of the Silurian epoch, and two groups, *Ganoidei* and *Placoidei*, culminated in the Devonian seas. The *Teleostei* now dominate. *Crossopterygian*, *Acanthodian*, and *Placodermal* (Elasmobranch) forms were Carboniferous and Devonian.

REPTILIA commenced in the Carboniferous, were common in the Permian and Trias, and reached their maximum in the middle Mesozoic age—all three groups being represented. The Amphibian Reptiles first appear in Upper Palæozoic time as Labyrinthodon.

MAMMALIA—first known in the Reptilian (Triassic) age through the Marsupialia (Microlestes), Mammals — were the highest race in the Mammalian or Upper Tertiary period. The Cretaceous rocks have as yet yielded no Mammalia; the Jurassic rocks contain *Amphitherium* and *Phascolotherium*, and the *Placental Stereognathus*. The fresh-water group (*Purbeck*) number nearly twenty species of Marsupials—*Plagiaulax*, *Triconodon*, *Achyrodon*, &c.

PLANTS (ALGÆ OR SEA WEEDS). — Probably these were the earliest group of plants, and may have preceded animal life. This group is rare in Britain. Acrogens and conifers first appear in the Upper Silurian rocks. In the Devonian period plants were very abundant, especially in America and Australia, the Gymnospermous Exogens being represented by the remains of the conifers *Dadoxylon* and *Ormoxylon*, the lycopodiaceæ by *Lepidodendron*, *Cordaites*, *Lepidophloios*, &c. The acrogens greatly predominated during the coal measures, associated with the conifers *Araucarioxylon*, *Dadoxylon*, &c. The Cycadeæ attained their maximum in the Reptilian age (Jurassic and Cretaceous portion). Dicotyledonous or Angiospermous Exogens commenced (so far as we know) at the close of the Reptilian age (Cretaceous), and greatly increased along with palms, as the Tertiary mammalia predominated.

Adolphe Brongniart proposed a division of the stratified rocks in accordance with the presence, development, and distribution of plants, naming the Palæozoic period the "*Age of Acrogens*;" the Triassic and Jurassic periods (Lower Mesozoic) the "*Age of Gymnosperms*;" and the Cretaceous (Upper Mesozoic) and Tertiary periods, the "*Age of Angiosperms*." This generalisation, however, was too restricted to be generally received.

Subdivisions into Periods and Epochs.—These vary in different countries according to the known development and succession of life

[1] The sub-kingdom *Cœlenterata* is the modern representative of the *Radiata* of Cuvier; but from the latter the Echinodermata and Scolecida have been removed, and now constitute the Annuloida. The sub-kingdom *Protozoa* and *Polyzoa* are now properly placed, the latter being relegated to the Mollusca.

over given areas. Geological history has no beginning; we cannot trace even the sedimentary rocks to their earliest commencement, owing to the incompleteness of the geological record, and its imperfect and fragmentary character.

Each of the above seven Epochs, Ages, or "Times" is subdivided into Periods, and each period was manifested by the formation of a definite and now recognised series of stratified rocks.

The following Table represents the *great periods* as they are known to have succeeded each other, and gives the order in which they were deposited either in one general area, or in many, their sequence being true when rightly understood:—

TERTIARY OR CAINOZOIC EPOCH.

1. Pleistocene or Post-Pliocene Period.
2. Pliocene Period.
3. Miocene Period.
4. Eocene Period.

SECONDARY OR MŒSOZOIC EPOCH.

5. Cretaceous Period.
6. Jurassic Period.
7. Triassic Period.

PRIMARY OR PALÆOZOIC EPOCH.

8. Permian Period.
9. Carboniferous Period.
10. Devonian Period.
11. Silurian Period.
12. Cambrian Period.
13. Laurentian Period.

We have thus the broad divisions of the Organic, Fossiliferous, or Stratified Rocks epitomised in the above thirteen great periods. These, for purposes of study, are again more minutely subdivided, and the following Table shows these thirteen periods broken up into thirty-eight Groups or formations. The classification of the fossiliferous rocks may be carried still further, and the whole series of the British stratified rocks may be arranged under no less than 140 Sub-formations, each of which contains organic remains peculiar to itself:—

TABLE I.

ABRIDGED TABLE OF FOSSILIFEROUS STRATA.

1. RECENT.	POST-TERTIARY or PLEISTOCENE.			
2. POST-PLIOCENE.				
3. NEWER PLIOCENE.	PLIOCENE or UPPER TERTIARY.	TERTIARY or CAINOZOIC.		NEOZOIC.
4. OLDER PLIOCENE.				
5. UPPER MIOCENE.	MIOCENE or MIDDLE TERTIARY.			
6. LOWER MIOCENE.				
7. UPPER EOCENE.	OLIGOCENE.[1]			
8. MIDDLE EOCENE.	EOCENE or LOWER TERTIARY.			
9. LOWER EOCENE.				
10. MAESTRICHT and FAXOE BEDS.	CRETACEOUS.	SECONDARY or MESOZOIC.		
11. WHITE CHALK (Upper and Lower).				
12. UPPER GREENSAND (Cénomanien).				
13. GAULT (Albien).				
14. LOWER GREENSAND (Neocomian).				
15. WEALDEN.				
16. PURBECK BEDS.	JURASSIC.			
17. PORTLAND OOLITE.				
18. KIMMERIDGE CLAY.				
19. CORALLIAN BEDS.				
20. OXFORD CLAY And Kellaways Rock).				
21. GREAT or BATH OOLITE (With Cornbrash and Forest Marble.				
22. INFERIOR OOLITE.				
23. UPPER } 24. MIDDLE } LIAS. 25. LOWER }				
26. UPPER } 27. MIDDLE } TRIAS. 28. LOWER }	TRIASSIC.			
29. PERMIAN.	PERMIAN.	PRIMARY or PALÆOZOIC.	PALÆOZOIC.	
30. COAL-MEASURES (And Millstone Grit).	CARBONIFEROUS.			
31. CARBONIFEROUS LIMESTONE.				
32. UPPER } 33. MIDDLE } DEVONIAN and OLD RED SANDSTONE. 34. LOWER }	DEVONIAN.[2]			
35. UPPER } 36. LOWER } SILURIAN.	SILURIAN.			
37. UPPER } 38. LOWER } CAMBRIAN.	CAMBRIAN.			
39. UPPER } 40. LOWER } LAURENTIAN.	LAURENTIAN.			

[1] The Hempstead, Bembridge, Osborne, and Headon Beds are probably of the same age as the Oligocene of Germany

[2] Including the Old Red Sandstone.

TABLE II.

TABULAR OR SYNOPTICAL VIEW

OF

THE KNOWN FOSSILIFEROUS STRATA,

SHOWING THE ORDER OF SUPERPOSITION OR STRATIGRAPHICAL SUCCESSION OF THE CHIEF GROUPS.

POST-TERTIARY OR QUATERNARY.[1]

POST-TERTIARY or QUATERNARY.

1 RECENT.

- BRITISH—Peat with human and other remains and marine strata, with canoes, in the estuary of the Clyde, and alluvia now forming.
- FOREIGN—Danish peat (kitchen-middens), with implements of bronze and stone.
- Lacustrine mud, with remains of Swiss lake-dwellings and implements of stone and metal.
- Marine strata enclosing Temple of Serapis, at Puzzuoli, &c.
- Lacustrine strata.

Shells and mammalia, all of living species.

2 POST-PLIOCENE.

- BRITISH—Loam of caves, with flint knives and bones of extinct and living quadrupeds.
- Valley gravels, or ancient alluvium of the Thames and Ouse, with stone implements.
- Glacial drift of Scotland, with marine shells.
- Boulder-clay formation of Norfolk cliffs.
- Forest-bed of Norfolk cliffs, with bones of elephant, &c.
- Glacial drift of Wales with marine fossil shells, nearly 1400 feet above sea-level, on Moel Tryfaen.
- FOREIGN—Ancient Valley gravels of Amiens, with flint implements and bones of extinct mammalia.
- Loess of Rhine.
- Ancient Nile-mud forming river-terraces.
- Marine strata of Sardinia, 300 feet above sea-level.
- Loam and breccia of Liege caverns, with human remains, and bones of extinct and recent mammalia.
- Australian cave breccias, with bones of extinct marsupials.
- Glacial drift of Northern Europe.
- Post-glacial freshwater deposits of North America with remains of Mastodon.

Shells, recent mammalia in part extinct.

[1] Embracing Recent and Pre-Historic, Post-Glacial, and Glacial deposits. *The Recent and Pre-Historic beds* comprise blown sand and shingle, alluvium and river deltas, marine strata of the Clyde, *Scrobicularia* clays, submerged forests, and peat bogs of Ireland and England.

The Post-Glacial deposits include raised beaches, cave-remains, river-valley gravels, brick earths, and fresh water clays, high-level gravels and clays with flints covering chalk, probably also the Kaimes of Scotland and the Escars of Ireland and later moraines.

The Glacial beds represent the upper boulder clay or till, the upper, middle, and lower glacial drift of the East of England, erratic blocks and boulders, &c.

The Pre-Glacial series include the forest beds of Norfolk and Suffolk (Cromer, &c.), and the mammaliferous clay of Kissingland with overlying forest bed.

TABLE II.—*Continued.*

TERTIARY OR CAINOZOIC.

PLIOCENE or UPPER TERTIARY	3 NEWER PLIOCENE.	BRITISH—Norwich crag, marine, with shells of extinct species, bones of *Mastodon arvernensis*, &c., 20 feet. Chillesford beds, with marine shells, extinct, and those of living species chiefly Arctic, 15 feet. Bridlington Beds, marine Arctic fauna. FOREIGN—Tuffs of Ischia, Cone of Monte Somma, Eastern base of Mount Etna. } Marine shells of which many of the species are extinct. Calcareous and argillaceous strata and volcanic tuffs of Sicily, with shells. Lacustrine strata of Upper Val d'Arno, with *Mastodon arvernensis*, &c.
	4 OLDER PLIOCENE.	BRITISH—Red crag of Suffolk, marine shells, some of northern forms, 30 feet. White or coralline crag of Suffolk, testacea less northern, 40 feet. FOREIGN—Upper and middle Antwerp crag, bones of cetacea numerous. Subapennine marls and sands. Aralo-Caspian brackish-water formations.
MIOCENE or MIDDLE TERTIARY.	5 UPPER MIOCENE.	BRITISH—Wanting in the British Islands. FOREIGN—Edeghem beds, Antwerp, with many extinct species. *a.* Diest sands. Bolderberg beds of Belgium. Faluns of Touraine, with testacea of sub-tropical character, *Dinotherium*, &c. Faluns, proper, of Bordeaux. Freshwater strata of Gers, with remains of quadrumana. Sands of Eppelsheim, with falunian quadrupeds. Vienna basin, with shells nearly all of extinct species, and *Dinotherium*. Beds of the Superga near Turin. Deposit at Pikermé, near Athens, with fossil pachyderms and apes. Swiss Œningen beds, rich in plants and insects. Marine molasse, Switzerland. Siwâlik hills, with freshwater shells and extinct quadrupeds. Marine strata of the Atlantic border in the United States. Volcanic tuff and limestone of Madeira, the Canaries, and the Azores.
	6 LOWER or OLIGOCENE in part.	BRITISH—Hempstead and the Bembridge, Osborne, and Headon beds, Isle of Wight. Lignites and clays of Bovey Tracey?, plants of sub-tropical character,[1] 120 feet. Isle of Mull leaf-beds volcanic tuff. No mollusca. 130 feet. FOREIGN—Calcaire de la Beauce, &c. Grès de Fontainebleau. Lacustrine strata of the Limagne d'Auvergne, and of the Cantal. Lower marine and brackish strata of Bordeaux, with *Cerithium plicatum*, &c. Mayence basin, Littorinella limestone, and marls with *Cyrena semistriata*, &c. Radaboj beds of Croatia, with fossil plants and insects. Brown coal of Germany. Lower molasse of Switzerland, freshwater and brackish, with sub-tropical flora. Rupelian beds of Dumont, with Middle Limburg (Kleyn Spawen) beds (Upper Tongrian of Dumont), with marine and freshwater shells. Lower Limburg (Lower Tongrian of Dumont), with marine shells, many species common to Upper Eocene.

TABLE II.—*Continued.*

EOCENE or LOWER TERTIARY.	7 UPPER EOCENE.	BRITISH—1. Bembridge, fluvio-marine strata, with *Palæotherium*, &c.,[1] 115 feet. Osborne or St. Helen's series,[1] 70 feet. Headon series, with marine and freshwater shells,[1] 200 feet. Barton clay, with nummulites,[1] 300 feet. FOREIGN—1. Gypsum of Montmartre (freshwater), with *Palæotherium*. Calcaire silicieux, or Travertin inférieur. Grès de Beauchamp or Sables moyens.
	8 MIDDLE EOCENE.	BRITISH—1. Bagshot and Bracklesham beds. 1000 feet. White clays of Alum Bay and Bournemouth, with plants of tropical genera. FOREIGN—1. Calcaire grossier, miliolite limestone. Soissonnais sands, or Lits coquilliers, with *Nummulites planulata*. Claiborne beds of United States, with *Orbitoides* and *Zeuglodon*.
	9 LOWER EOCENE.	BRITISH—1. London clay proper, shells, fish, and plants of sub-tropical types. 500 feet. Plastic or mottled clays of Woolwich, fluvio-marine, 200 feet. Thanet sands, with *Pholadomya*, &c., 90 feet. FOREIGN—1. Argile de Londres near Dunkirk. Argile plastique, with *Gastornis parisiensis*. Sables de Bracheux, with *Arctocyon primævus*.

SECONDARY, OR MESOZOIC.

CRETACEOUS.	10 UPPER CRETACEOUS.	BRITISH— White chalk with flints, marine, 1000 feet. Chalk marl, marine, 400 feet. Upper greensand—fire stone of Surrey, marine, 100 feet. Gault—dark blue marl of south-east of England. Blackdown beds of littoral origin, 300 feet. FOREIGN—1. Maestricht beds, with *Mosasaurus*, 100 feet. Faxoe chalk with *Nautilus danicus*, &c., 100 feet. White chalk of France, Sweden, and Russia. Pläner-kalk of Saxony. Sands and clays of Aix-la-Chapelle, with dicotyledonous angiosperms. Quader sandstein of Germany. Gault of the Loire. Hippurite limestone of South of France. New Jersey U.S. sands and marls. Siliceous limestone of Texas.
	11 LOWER CRETACEOUS or NEOCOMIAN.	BRITISH—1. Ferruginous and green sands. Sandgate beds, 170 feet, Folkstone beds. Hythe beds, with Kentish rag, or calcareous stone, 60 feet. Atherfield beds, marine, with *Perna Mulleti*, 50 feet. — Upper Neocomian. Speeton clay with *Ammonites noricus* and *A. astierianus*. — Lower Neocomian, 1000 ft. Weald clay of Surrey, Kent, and Sussex, freshwater, with *Cypris*. Hastings sands (Tunbridge and Ashburnham beds, freshwater, *Iguanodon mantelli*, 700 feet.) FOREIGN—1. Neocomian of Neufchâtel. Wealden beds of Hanover and Belgium with Iguanodon.

[1] The Hempstead, Bembridge, Osborne, and Headon beds may be regarded as representing, if not the true equivalent of, the oligocene beds of Germany. The Bovey beds may be of higher antiquity (Eocene).

TABLE II.—*Continued.*

JURASSIC.	12 UPPER JURASSIC.	BRITISH—Upper Purbeck beds, freshwater, Purbeck marble. Middle Purbeck fluvio-marine, with numerous marsupial quadrupeds and Reptilia, &c. Lower Purbeck freshwater, with intercalated dirt bed. (300 feet.) Portland stone and sand, 180 feet. Kimmeridge clay, bituminous shale, 600 feet. FOREIGN—Marnes à gryphées virgules of Argonne. Lithographic stone of Solenhofen with *Archæopteryx*.
	13 MIDDLE JURASSIC.	BRITISH—Corallian beds of Berkshire, Wilts, and Yorkshire, 80 feet. Oxford clay, with Belemnites and Ammonites, 600 feet. Kellaway rock of Wilts and Yorkshire, 60 feet. FOREIGN—1 Nerinæan limestone of the Jura. Diceras limestone of the Alps.
	14 LOWER JURASSIC.	BRITISH—Cornbrash and forest marble of Wilts and Gloucester, 60 feet. Great oolite of Bath and Bradford, with Apiocrinites, &c. Stonesfield slate with marsupials and *Araucaria*. (250 feet.) Fuller's earth with *Ostrea acuminata*, 80 feet. Inferior oolite, 300 feet.
	15 LIAS.	Upper lias, argillaceous, and arenaceous, with *Ammonites striatulus*, and *A. serpentinus*, 350 feet. Shale and limestone, with *Ammonites bifrons*. Marlstone series, or middle lias, divisible into three zones with characteristic *Ammonites*, *A. spinatus*, *A. margaritatus*, and *A. Davæi*, 200 feet. Lower lias, divisible into eight zones, *Ammonites raricostatus* in the highest, and *A. planorbis* in the lowest zone, 600 feet.
TRIAS or NEW RED SANDSTONE. (*Nouveau grès rouge.*)	16 UPPER TRIAS.	BRITISH—Penarth, Rhætic or *Avicula contorta* beds—White lias, and black shales with fish of the genera *Sargodon*, *Saurichthys*, and *Hybodus*, with *Microlestes*, &c., 100 feet. Red clay, with thick beds of salt, at Northwich, in Cheshire, 2000 feet. Dolomitic conglomerate of Bristol, with *Thecodontosaurus*, &c., 40 feet. FOREIGN—Keuper beds of Germany, with *Microlestes* and fish of the genera *Hybodus*, &c., 1000 feet. St. Cassian or Hallstadt beds, with rich marine fauna. Coalfield of Richmond, Virginia, with *Estheria ovata* and plants resembling those of European Keuper. Chatham coalfield, North Carolina, with *Dromatherium*.
	17 MIDDLE TRIAS.	BRITISH—Wanting. FOREIGN—Muschelkalk of Germany, with *Encrinus liliiformis* and *Placodus gigas*, 600 feet.
	18 LOWER TRIAS.	BRITISH—New red sandstone of Lancashire and Cheshire, with *Labyrinthodon* and footprints of *Cheirotherium*, 1500 feet. FOREIGN—Bunter-sandstein of Germany, with footsteps of *Labyrinthodon*, 1500 feet. Red sandstone of Connecticut Valley, with footprints of birds and reptiles.

TABLE II.—*Continued.*

PRIMARY OR PALÆOZOIC.

UPPER PALÆOZOIC.	PERMIAN.	19 PERMIAN.	BRITISH—1. Concretionary magnesian limestone of Durham and Yorkshire. Brecciated magnesian limestone of Tynemouth cliff, &c. Fossiliferous magnesian limestone, with *Fenestella retiformis.* Compact magnesian limestone. Marl-slate of Durham, with heterocercal fish (Palæoniscus), 60 feet. Lower sandstones, with plants resembling those of the coal, but differing in species, 200 feet. FOREIGN—1. Stinkstein of Thuringia. Rauchwacke, *ibid.* Dolomite or Upper Zechstein. Zechstein or Lower Zechstein. Mergel-schiefer or Kupferschiefer, with *Protorosaurus.* Roth-liegendes of Thuringia, with *Psaronius.* Magnesian limestones, &c., of Russia.	800 feet.
MIDDLE PALÆOZOIC.	CARBONIFEROUS.	20 UPPER CARBONIFEROUS.	BRITISH—Coal measures of South Wales, &c., with underclays enclosing *Stigmaria.* Coal measures of Coalbrook Dale. Millstone grit, 1000 feet. Coal measure rocks of Ireland, 6000 feet. FOREIGN—St. Etienne coalfield, with erect fossil trees. Coalfield of Saarbruck with *Archegosaurus.* Carboniferous strata of Nova Scotia, with fossil forests, and land-shell *Pupa vetusta.* Appalachian coalfield, 720 miles long and 180 miles wide, with footprints of Cheirotherium.	15,000 feet.
		21 LOWER CARBONIFEROUS.	BRITISH—Carboniferous limestones of Wales, West and North of England, with marine fossils, chiefly mollusca corals and crinoids. Same in Derbyshire and Ireland, with fish-beds. Carboniferous limestone of Scotland alternating with coal-bearing sandstones. Calciferous beds, Scotland. FOREIGN—Carboniferous limestone of Belgium. Kiesel-schiefer and Jungere Grauwacke of Germany, with *Posidonomya Becheri.* Gypseous beds and Encrinital limestone, Nova Scotia.	2000 feet.
	DEVONIAN or OLD RED SANDSTONE (*Terrain Devonien, Vieux grès rouge*).	22 UPPER DEVONIAN.	BRITISH—Yellow sandstone of Dura Den, with *Glyptolæmus, Holoptychius, Phaneropleuron,* &c.; and of Kilkenny with fossil fish and plants. Pilton group of North Devon, with *Spirifera disjuncta.* Pickwell down beds of Morte Bay, North Devon. Petherwyn group of Cornwall, with *Clymenia* and *Cypridina.* FOREIGN—Clymenien-kalk and Cypridinen-schiefer of Germany. Limestones of the Fichtelgebirge, with trilobites of the genera *Bronteus* and *Phacops,* &c. Catskill and Chemung group of New York, U.S.	
		23 MIDDLE DEVONIAN.	BRITISH—Sandstones of Forfarshire and Perthshire, with Holoptychius, &c. Bituminous schists of Gamrie, &c. Slates and sandstones of North Devon. Ilfracombe beds with many trilobites, corals, and cephalopoda distinct from Upper Devonian. Torquay, Plymouth, and Newton Bushel limestones, rich in corals, &c. FOREIGN—Eifel limestone, with underlying schists, containing *Calceola,* &c. Corniferous formation of Western Canada and New York. Devonian strata of Russia.	

TABLE II.—*Continued.*

MID. PALÆ.		24 LOWER DEVONIAN.	BRITISH—Arbroath beds, with *Cephalaspis*, *Pterygotus*, and *Parka*. Lower sandstones of Caithness, with *Pterygotus*. Sandstones and slates of the Foreland and Linton. Sandstones and slates of South Devon and Cornwall, with broad-winged Spirifers. FOREIGN—South African Devonian strata, with *Homalonotus*, &c. Oriskany sandstone of Western Canada and New York.
LOWER PALÆOZOIC.	SILURIAN.	25 UPPER SILURIAN.	BRITISH—Upper Ludlow formation. Downton sandstone and tile stones, with bone-bed in the upper part; grey sandstone, with *Rhynchonella*, &c., 1200 feet. Lower Ludlow formation, comprising Aymestry limestone and Ludlow shale, with oldest known fish remains, 1050 feet. Wenlock limestone, with trilobites, &c., 150 feet. Wenlock shale, with crinoidea and mollusca, rich in corals and Brachiopoda, &c., 1400 feet. Woolhope limestone and grit, 150 feet. FOREIGN—Niagara limestone, with *Calymene*, *Homalonotus*, &c.
		26 LOWER SILURIAN.	BRITISH—Upper Llandovery, comprising Tarannon shale and May-hill sandstone and limestone, with *Pentamerus lævis*, &c., 1400 feet. Lower Llandovery rocks, 1000 feet. FOREIGN—Clinton group of America, with *Pentamerus lævis*, &c. Silurian strata of Russia, with *Pentameri*. BRITISH—Caradoc or Bala beds, with *Trinucleus Concentricus*, &c., 7000 feet. Llandeilo flags, with graptolites and interstratified volcanic tuffs, 5000 feet. Arenig or Quebec group, with *Didymograptus geminus*, &c., and interstratified volcanic tuffs. FOREIGN—Ungulite or Obolus grit of Russia. Hudson River group and Trenton limestone of North America, with *Trinucleus*, &c., and Black River limestone, with large *Orthoceras*. Orthoceras limestone of Sweden.
	CAMBRIAN.	27 UPPER CAMBRIAN (Primordial zone of Barrande).	BRITISH—Tremadoc slates, with trilobites, 2000 feet. Lingula flags, with *Lingulella Davisii*, *Paradoxides*, &c., 5000 feet. FOREIGN—"Primordial" zone of Bohemia, with *Paradoxides*, &c. Alum schists of Sweden and Norway. Potsdam sandstone, with *Dikelocephalus* and *Obolella*.
		28 LOWER CAMBRIAN (Longmynd Group).	BRITISH—Harlech grits, with *Arenicolites sparsus*, &c., 6000 feet. Longmynd rocks, 20,000 feet. Llanberis slates, 3000 feet. FOREIGN—Huronian series of Canada.
	LAURENTIAN (*Pre-Cambrian*).	29 UPPER LAURENTIAN.	BRITISH—Fundamental gneiss of the Hebrides? Hypersthene rocks of Skye? FOREIGN—Labradorite series north of the river St. Lawrence in Canada. Adirondack mountains of New York.
		30 LOWER LAURENTIAN.	BRITISH—Wanting. (?) FOREIGN—Beds of gneiss and quartzite, with interstratified limestones, in one of which, 10,000 feet thick, occurs *Eozoon Canadense*, the oldest known fossil.

It is important to place in tabular form the succession of the Palæozoic rocks of America. [Their general synonyma appear under the foreign groups in the foregoing table, but for ready reference they are here given separately.] North American strata above the Permian are by name the same as in Britain and Europe generally,

TABLE III.

PALÆOZOIC ROCKS OF NORTH AMERICA.

Ages.		Periods.	Formations.
		Permian.	Permian.
CARBONIFEROUS AGE, or AGE of AGROGENS.		Carboniferous	Upper Coal Measures. Lower Coal Measures. Millstone Grit.
		Sub-Carboniferous.	Upper. Lower.
DEVONIAN AGE, or AGE of FISHES.		Catskill.	Catskill.
		Chemung	Chemung. Portage.
		Hamilton	Genesee. Hamilton. Marcellus.
		Corniferous	Corniferous. Schoharie. Cauda-Galli.
SILURIAN AGE, or AGE of INVERTEBRATA.	UPPER SILURIAN.	Oriskany.	Oriskany.
		Lower Helderberg.	Lower Helderberg.
		Salina.	Salina.
		Niagara.	Niagara. Clinton. Medina. Oneida Conglomerate.
	LOWER SILURIAN.	Trenton	Cincinnati. Utica. Trenton.
		Canadian	Chazy. Quebec. Calciferous.
		Primordial or Cambrian	Potsdam. Acadian.
		Archæan.	Archæan.

Thickness of the Stratified Rocks.—The thickness of the stratified rocks, as far as can be reliably ascertained, is about twenty miles, or 100,000 feet. This includes the sum of the whole if they occurred in one pile, which they do not, as the series is *nowhere complete in one section*, place, or region. In the British Islands, where the stratified rocks are more complete than in any other area, the thickness to the top of the Silurian is over 60,000 feet; to the top of the Carboniferous and Permian, or summit of the Palæozoic, about 85,000 feet; and to the close of the whole, ending with the Upper Tertiaries, about 100,000 feet. On the Continent the *Secondary and Tertiary rocks* are thicker than in Britain, and at least 20,000 feet exist above the Palæozoic series. The rocks of America nowhere reach the sum of the thickness above stated. In Pennsylvania, where they are the thickest, they do not exceed 40,000 feet; the rocks of New York, *down to the Archæan*, about 13,000 feet. It is also remarkable, as bearing upon the old

and therefore need no special notice. They are not physically well represented in America, but possess a rich and varied fauna; especially is this the case with the vertebrata between the Trias and the Pliocene series:—

physical geography of the American continent, that the grand physical features of that area were early defined; and that through all time, from the close of the Archæan period, if not before, the ranges of land which are near the mountain chains were the boundaries between great continental basins, that were in a marked degree independent in the progress of rock-making and of life.

CHAPTER II.

PRE-CAMBRIAN PERIOD.

Archæan[1] *or Azoic Rocks.*

BENEATH the oldest organic or life-bearing stratified rocks of the entire globe, we have evidence of still older crystalline schists and massive metamorphosed strata. These rise to the surface, and now appear by means of two agencies—(1) either through elevation from their original and deeply-seated position, or (2) through exposure to long-continued denudation, which has in course of time removed the superincumbent strata, thus laying bare the earlier framework or basis of the igneous, unstratified, and oldest stratified series.

These (probably) fundamental rocks are considered by some as portions of the primeval mass or crust of the globe, affording us an insight into what we may believe this congealed nucleus to be; while other physicists, again, regard them as metamorphosed, stratified, or sedimentary rocks, belonging to the earliest periods of geological time, long prior to the deposition of the so-called Lower Cambrian and Silurian Rocks. Whatever their origin, we are bound to admit them to be at present the *oldest* known rocks.

Archæan Time.—It is at all times difficult to establish the true chronology of deposits of high antiquity, for unconformity below succeeding or newer formations does not conclusively show the real but only the relative age of the strata in question, nor can it be said that lithological or petrological characters are decisive as to age. Dana defines Archæan time as "including strictly in its commencement an Azoic age, or the era in which the physical conditions were incompatible with the existence of life. . . . Therefore," he says, "this era, so far as we know, is without recognisable records, for no rocks have yet been known to be earlier in date than those which are now supposed to have been formed since life first began to exist. . . . These Archæan rocks are the only universal formation. They extend over the whole globe, and formed the floor of the ocean, and the material of all emerged land when life first appeared. The thickness which they acquired during the long era, from the time of the first-formed crust, can never be known."

[1] A term first proposed by James D. Dana, since generally received and adopted both in America and Britain (Manual of Geology, pp. 146–161).

Dana thus employs the term "Archæan" in time, to express in full meaning that era in the physical development of the earth, when life was not, so far as we know. Little, however, is known of that vast group of rocks which we call pre-Cambrian, adopting the term as used in this country, on the Continent, and in America, for rocks affording us no life-history or recognisable records.

Dana's Four Eras.—Dana again assumes and endeavours to show that four eras preceded the Laurentian period:—

A First or Molten Era subsequent to that of the presumed original nebulous state.

A Second Era, one of solidification and consolidation through cooling, when the earth became solid at the centre; later on, atmospheric vapours became condensed and probably universal; water covered all. The cooling and contracting of the sphere resulted in oceanic depressions in special areas, and our continents were shadowed forth and contoured, but as yet no life can be chronicled.

The Third Era may have given us surface reliefs; stratified deposits were formed.

The Fourth Era probably saw the beginning of life, which occurred when the temperature of the oceanic waters may have stood at 200° F. With this fourth era we may associate the Eozoonal serpentines.

In the British Islands we have yet to find that type of Laurentian rock which yields either of the two great limestones of Canada,—the so-called Fundamental Gneiss of Scotland, Malvern, and Ireland, having no affinities with the Eozoonal and graphitic group of the North-American continent, and being doubtless of vastly younger date.

Areas and Positions of Archæan Rocks.—The largest areas of Archæan rocks now exposed are in the northern parts of Europe and North America. Elsewhere they rise to the surface as isolated patches surrounded by younger formations. In regard to the position and exposure on the surface, Dana classifies them in three groups as under:—

1. "Those which have always remained uncovered.
2. "Those which have been covered by later strata, but from which these superimposed beds have been washed away (denuded) with but little disturbance.
3. "Those once covered like the last, but which in the course of time and the upturnings of mountain-making have been pushed upwards among the displaced strata, and have thus been brought to light."

Texture of Archæan Rocks.—The Archæan rocks appear everywhere to exhibit the same general characters, gneissic and schistose, having associated banded, hornblendic, and pyroxenic rocks, with dolomite limestone, serpentine, quartzite, hæmatite and graphite, &c., &c. As regards any order of succession, none appears to have been definitely observed, though the parts that may be considered as Lower and Upper may differ in texture. The Lower, which appear

to be coarser and more granitoid, are chiefly gneiss, having bands of granite, while the Upper portions are finer-grained, or less coarsely crystalline, and composed of mica-schists, talc-schists, chlorite-schists, and clay slates. In central Europe there appears again to be a gradation, from the lowest up to the latest portion of the thick Archæan series.

Graphite Iron Veins.—Large quantities of graphite occur throughout the Archæan rocks of Canada and the northern parts of the United States. This mineral is found partly in veins, and laminæ in the limestone, and also in the form of independent layers. Dr. Dawson of Montreal estimates the aggregate amount of graphite in one band of limestone, in the Ottawa district, as not less than from 20 to 30 feet, and he believes that there is as much carbon in the Laurentian as in equivalent areas of the Carboniferous system. Some of the pure bands of graphite are comparable to beds of coal, and no other source for their origin can be imagined than the decomposition of carbon dioxide, by living plants. Still further evidence in favour of organised existence during Archæan times in the North American area, has been adduced from the thick and abundant masses of iron ore associated with the Laurentian rocks of Canada and the United States. Dr. Sterry Hunt has called attention to these ores as proving the precipitation of iron by decomposing vegetation, during the Laurentian period, on a more gigantic scale than at any subsequent geological epoch. Some of the beds of magnetic iron range up to 200 feet in thickness.

Distribution of Archæan Rocks.—The history of the space distribution of these ancient masses is essential to a correct understanding of certain areas. Central Europe, Scandinavia, Australia, New Zealand, and America, are regions where these Archæan rocks play an important part in the physical structure of the country.

European Area: Scotland.—In no part of the European area are the Archæan rocks better seen than in the north-west of Scotland. They strike N.N.W., and are unconformably overlaid by all other rocks of the Scottish Highlands. They constitute nearly the whole of the Outer Hebrides, and much of the western parts of the counties of Sutherland and Ross. They are the Fundamental or Lewisian Gneiss of Murchison, and consist of a tough, massive gneiss, usually hornblendic, with bands of hornblende rock, *hornblende schist*, *actinolite schist*, *eclogite*, *mica schist*, *sericite schist*, and other crystalline rocks.[1] The lower portions of the series are on the whole more massive than the upper, and more traversed by *Pegmatite* veins; the beds of the upper division are thinner, more schistose, and with a great diminution in the quantity of *Pegmatite*. On the lowest calculation, the Laurentian rocks of western Scotland cannot be less than 20,000 feet thick.

Ireland.—Recent observations by Professor Hull and his colleagues in Ireland, have shown that in Donegal there exists a massive granitic gneiss, which they identify with the fundamental gneiss of the

[1] Geikie, "Text-Book of Geology," p. 640.

north-west of Scotland, and which is unconformably covered by the quartzites, limestones, and other crystalline rocks, shown by Harkness to be continuations of the similar series of the Lower Silurian masses of the Scottish Highlands. The characteristic red Cambrian sandstones and conglomerates that overlie the Scotch Laurentians have not, however, been detected in Ireland.—*Geikie.*

Scandinavia.—The researches of Keilhan, Kjerulf, Törnebohm, Karl Petersen, and others, have shown that the Archæan rocks of Scandinavia consist chiefly of gneiss, quartz, hornblende schist, pegmatite, syenite, labradorite-rock, serpentines, and many other varieties. Thin bands of limestone occasionally occur in the gneiss near Christiansand, where numerous minerals have been found. *Apatite, titaniferous iron,* and *hæmatite* form an important feature in the Archæan series of Norway. The same rocks range into Sweden, where at Dannemora Filipstad occur thick beds and lenticular masses of iron ore, which are extensively worked.

Central Europe.—It is probable that Archæan rocks range through Finland into the north-west of Russia, appearing as the nucleus of the Ural chain of mountains. They appear in Central Europe as islands rising in the midst of more recent formations. "The finest sections are to be studied southward from Dresden, through Bavaria and Bohemia, between the valley of the Danube and the head waters of the Elbe." They may be divided into two well-marked groups—(*a*) "red gneiss, containing pink orthoclase and white potash-mica, covered by (*b*) grey gneiss, containing white or grey felspar and dark magnesia-mica."

Bavaria.—The Hercynian gneiss and associated limestones also appear to be Archæan, and are believed to contain two species of Eozoon—*E. Bavaricum* and *E. Bohemicum.*

North America.—The Archæan rocks are greatly developed in North America, covering a vast area from the Arctic circle southwards, stretching from Labrador on the north-east to Lake Superior and the Arctic regions on the north-west, an area which appears to have been dry land ever since the Archæan era.

United States.—The Adriondack area, in Northern New York, probably belongs to this era, covering much of New York State, and Michigan, south of Lake Superior, which were probably islands in the continental sea, before the Silurian age began.

The Appalachian areas also probably belong to this era. Commencing in Dutchess County, they cover much of New York, the blue ridge of Pennsylvania and Virginia, the Laramic range and other ridges of the Rocky Mountains.

On the Atlantic coast, much of Newfoundland, Nova Scotia, and Eastern New England, Arkansas, and Texas are Archæan.

Canada.—It is to British North America, however, that we must look mainly for our knowledge of Archæan rocks.

In Canada they occupy an area of 200,000 square miles, and consist of two divisions, of which the lower is termed the Laurentian, the upper the Huronian system. The Laurentian derives its name

from its great development along the shores of the River St. Lawrence, and is estimated to be about 30,000 feet thick, but neither its top nor its base has been seen.

a. **Laurentian.**—*The Laurentian formation* again has been divided into two series, an Upper and a Lower.

1. *The Lower* is more than 20,000 feet thick, consisting chiefly of granite, orthoclase gneiss, bands of quartz rock and iron ore, interspersed with beds of limestone varying in thickness from 700 to 1500 feet, and containing *Eozoon Canadense*, the earliest known form of life.

2. *The Upper*, more than 10,000 feet thick, is composed chiefly of gneiss, and characterised by the occurrence of bands of Labrador felspar, with iron ore and limestone. This Upper division is *unconformable* upon the Lower. The Laurentian rocks were crystallised and disturbed before the Potsdam sandstones were formed or placed upon them. Like our Cambrian rocks, we know nothing of the land of which, or out of which, they were constructed.

b. **Huronian.**—Above the Laurentian rocks, in the region of Lake Huron, lies a vast mass of slates, conglomerates, limestones, and quartz rocks, attaining a thickness of from 10,000 to 20,000 feet. These are the *Huronian;* they contain no organic remains; some of the sandstones are ripple-marked, and the limestones do not contain any of the minerals common to the underlying Laurentian.—*Dana.*

Comparison of the Huronian Rocks of America and Europe.—Sir W. Logan, Sir R. Murchison, and others, regarded the Huronian rocks of Canada as being equivalent to the Cambrian of Western Europe, and Dr. Bigsby also accords them that position. The stratigraphical horizon is not far from that of the Cambrian rocks of Scotland and Wales, and they may in all probability be represented by the beds underlying the Menevian of St. David's, and also as constituting the rocks of Harlech, Llanberris, Bangor, and the Longmynds, or they may perhaps be considered as *between the Laurentian Gneiss and the Lower Silurian.* The Silurian, however, is transgressive, or overlapping in both hemispheres.[1] In Norway, the Huronian rocks are termed by Durocher "*the semi-crystalline schists,*" or "*the second group of Azoic formations,*" the first or lowest being the Fundamental or Laurentian gneiss of Murchison, Kjerulf, and Von Buch. In Northern Europe the Huronian rocks occupy six basins, in or upon the Fundamental gneiss (*the general base of all the rocks of Northern Europe*), viz.:—

1. At Nummendal and Haut-Tellemack.
2. In Central Scandinavia.
3. On the south-west coast of Norway.
4. On the sea coast between Drontheim and Sogne Fiord.
5. In Finmark.
6. Near Tornea at the head of the Gulf of Bothnia.[2]

[1] Bigsby, J. G. S., vol. xix. p. 45, "The Huronian Formation of Canada," &c.

[2] Mém. de la Soc. Géol. de France, vol. vi. ser. 2.

Their junction and unconformity with the Silurian is seen at Lake Miosen in Norway. In the paper referred to (1) Dr. Bigsby ably describes the Huronian rocks of America, Norway, and France.

Results of Inquiries into the Origin of the Archæan Rocks.—To trace out the development of the European, Asiatic, and American Continents from these Archæan times to the present, is one of the main purposes of geological history and study.

With this view, Dana has endeavoured to trace out the inception of the great American continent, foreshadowing its general topography, early mountain chains, and basins, and thus attempts to show that the evolution of the great "structure lines of the continent was early commenced," and that we may not be wrong in concluding "that the continents have always been continents, for although *portions* may at times have been submerged some thousands of feet, yet they have never changed places with the oceans."

To point to a beginning or definite commencement of the sedimentary rocks, however, has yet to be accomplished. Nowhere in the British Islands is their base to be seen. Recent investigations into the history and structure of the rocks composing the headland of St. David's, in South Wales, have determined the presence of life in sedimentary strata of greater age than any hitherto known, if we except the Eozoon-containing Laurentians of Canada. We may expect, therefore, that the progress of geological research will disclose to us fresh proofs of the presence of stratified rocks of yet higher antiquity than those now exposed in certain areas in England, Wales, and Ireland—rocks which rest upon highly metamorphosed masses of vast extent, of older date still, and in which all traces of original structural condition is obliterated.

To summarise the results of the labours and views of those who have carefully investigated and thought out any great physical question is at all times difficult; and perhaps there are few subjects on which men have theorised and differed more than on the history of life upon the globe. For time and life are two subjects that at once arrest the attention of all earnest students. Our knowledge of the commencement of either is as indefinite now as in the days of the earliest investigators. With the succession of sedimentary rock-masses in the outer framework of the globe, we are perhaps partly familiar, certainly so for given and known areas. There are, however, extensive regions yet unknown and unexplored, and remaining to be correlated with the known; and yearly, through research, are we reminded how insecure and uncertain is our base, how doubtful our succession, when attempted to be universally applied. Yearly some new light is thrown upon the obscure history of the earliest rocks with which we now believe ourselves acquainted. Both the early metamorphic and the lowest Palæozoic rocks, even in our own small area, are still waiting for final position and classification; the same may be said of much of Europe, America, Canada, India, and Australia.

Palæozoic time in Europe and Britain may have commenced with

the deposition of the so-called earliest Cambrian rocks; but where geographically, we know not—probably far to the west of Ireland and the British Islands, now under the waters of the Atlantic. The north-western coast of Scotland and Ireland, much of the north-west of England, and North and South Wales, all point to a region where we may believe that the earliest known sedimentary rocks of Western Europe and their life-contents had their commencement or origin.

We have hitherto discovered no life-remains in the Archæan rocks of the British Islands, our so-called Laurentians having none of the prevalent limestones, Eozoonal or otherwise, of the New York and Canadian rocks. To trace out the conditions of the northern hemisphere during Lower Cambrian times, both zoologically and physically, has been, and is still, one of the most difficult and important problems of modern geological research.[1] We have long known that the European Archæan rocks occupied an area of great extent, *long* before the Cambrian rocks were accumulated: remnants of this early land, or continent, are still visible and traceable in Spain, France, Scandinavia, Ireland, Scotland, England, and Wales. Gneiss, granitoid rocks, and occasional limestones formed the mass of this pre-Cambrian land, now exhibited to us in a greatly metamorphosed state, stratigraphically unconformable to the overlying Cambrian, and with a discordant strike north of latitude 30°. These rocks are visible on both sides of the Atlantic as far as the Arctic regions, representing portions of two continents, Europe and America, now separated by the North Atlantic.

First Appearance of Life.

Animal Life.—The earliest known life-form upon the globe occurs in the Laurentian rocks of North America. *Eozoon* was a compound species of *Foraminifera;* the masses formed by, or attributed to it, are several feet in diameter, and in the aggregate constitute great deposits or accumulations of limestone.

EOZOON CANADENSE.—Essentially consists of chambers arranged one above the other, regularly or irregularly, and perforated by septa; the sarcode occupying the tiers of chambers is bounded by a thin "proper wall," and perforated by minute tubes or pseudopodial foramina. The several tiers are connected by stoloniferous passages, which pass from one to the other, the canal system occupying and ramifying into the intermediate skeleton. In the Laurentian deposits the chambered calcareous skeleton is infiltered by certain silicates in solution, such as white pyroxene, serpentine, and loganite (a silicate of magnesia), these silicates now filling the chambers and spaces formerly occupied by the sarcode of the Eozoon, and thus revealing the *stolons* and *tubuli* through which were conveyed the pseudopodia to the exterior. The nearest living allies to *Eozoon* are the recent *Polytrema, Calcarina, Carpentaria,* and *Tinopus. Eozoon* has much affinity through its shell structure with the Nummulites; and its habit appears to have been to grow one layer over another, and to form reefs of limestone analogous to the existing coral reefs of the Pacific, growing or spreading prolately over the bed of the ocean. Dr. Dawson has minutely described Eozoon in his "Dawn of Life," a work devoted to the life history of this earliest known form.

[1] *Vide* Hicks, Geol. Mag. Dec. 2, vol. iii. p. 876, "On the probable Conditions under which the Palæozoic Rocks were deposited over the Northern Hemisphere."

Plant Life.—No remains of plants have been observed, although from other circumstances their existence has been inferred. No more difficult problem remains to be solved than the history of the first appearance of life on the globe. Is the Laurentian of North America, with its one known solitary organism, the oldest sedimentary rock existing? is *Eozoon canadense* the oldest known form of life? Research up to the present time has not revealed to us one of higher antiquity; neither has it even a truly associated form. No Plant, Protozoon or Annelid, accompanies this still mysterious progenitor of Palæozoic life. The Eozoic or Laurentian gneiss of Britain or Europe, has not yet yielded a semblance of anything approaching Protozoic affinities, although in the Hebrides, Norway, Sweden, Bohemia, and Bavaria these rocks have long been recognised.

That the Laurentian rocks are not the oldest is manifest; others of infinitely greater age yielded sediment to the Laurentian sea, and pabulum for the sustenance and material for the shelly structure of its supposed only inhabitant; but whether *Eozoon* had precursors or not, time will probably tell. If any older forms of animal life did exist, they cannot have belonged to much simpler types—

"Naked Protozoa would have left no sign of their existence, except probably minute traces of carbonaceous matter."

Plant life, however, may have preceded *Eozoonal*, and may thus have accumulated previous stores of organic matter.

We have already referred to the occurrence of graphite in the Archæan rocks, and its constituting twenty per cent. of some layers. This is strong evidence that plants of some kind were abundant, though, as suggested by Dr. Sterry Hunt, animal life may have afforded part of the carbonaceous material, and, perhaps, as large a part as vegetable life.

The presence of graphite in large deposits occurring both in beds and veins in the Laurentian rocks, clearly determines that its origin and deposition were contemporaneous with the mass or containing rock; the graphite, again, is associated with calcite, quartz, and orthoclase. It is not improbable that the "vein graphite" was introduced as a liquid hydrocarbon. Dr. Sterry Hunt believes it possible that it may have been produced in a state of aqueous solution.[1] In the lower Laurentians the quantity of graphite is enormous; its origin may have been due to the deoxidation of carbonic acid by living plants. That the graphitic matter of the Laurentian rocks was laid down or accumulated in beds like coal is improbable, no evidence whatever tending to show that there existed terrestrial vegetation. On the other hand, the hydrocarbon may have been due to diffused bituminous matter closely resembling "our bituminous shales and bituminous oil-bearing limestones." Research hitherto has failed to find traces of any organism save the *Eozoon;* no cryptogam has yet occurred; and we cannot imagine that, if of vegetable origin, the organic matter could have been so completely disintegrated and bituminised prior to being changed into graphite.

[1] Hunt, "Report of the Geological Survey of Scotland," 1866.

Another feature before alluded to, is the presence of terrestrial vegetation in the great beds of Laurentian iron ore which show subaerial decay, implying the "reducing and solvent action of substances produced in the decay of plants."

Finally, we have to take into account the limestone beds, which may also have proceeded from, or have been produced by the calcareous secretion of the lowest forms of vegetable life, allied to the *Nullipores* and *Corallines*.

At the utmost, however, we can only speculate upon the presence or condition of vegetation during the Archæan or pre-Cambrian era.

Probable conditions under which the Cambrian and Lower Silurian Rocks were deposited over the European Area.[1]

Old Continental Areas.—Wherever the base line of the so-called Cambrian rocks is seen throughout the European area, it is invariably found to rest unconformably upon earlier or older rocks.

These Eozoic, Archæan, or pre-Cambrian rocks in Europe, like the Laurentians of North America, indicate that large continental areas existed previous to the deposition of the Cambrian rocks.

It is highly probable that the European continent occupied at that time a larger surface than at present, and stretched from north of Norway and Lapland to the south coast of the Mediterranean. In an east-and-west line, it would extend from the 100-fathom line west of the British Islands to Asia; upon this plateau, now partly submerged, all the physical changes and vicissitudes which these islands and Europe have undergone have taken place. We have, however, no knowledge of the distance to which the continent may have extended to the west or south-west, nor the thickness of the deposits which may have taken place over such areas if they existed. In England, and especially in Wales, the Cambrian and Lower Silurian stratified deposits attain to a thickness of from 25,000 to 30,000 feet, exclusive of interbedded tuffs or contemporaneous trap rocks; whilst in Sweden the deposits *representative of these epochs* do not attain to 1000 feet; in Russia, again, they are of less thickness still; and in Bohemia they occupy an almost intermediate position both as regards thickness and order of deposition.

The close of the first great depression may be termed the *Menevian epoch*. This embraced a change of level extending over 1000 feet. It has been endeavoured to show (*op. cit.*) that the first Bohemian fauna was the onward passage of this or our *third* or Menevian fauna; and that the depression did not allow of the sea reaching the Bohemian basin until probably the whole of our Longmynd group had been deposited. This depression of the land was not, however, sufficient to allow the sea to spread over what we now call the Russian area; therefore we find no rocks of this age there deposited. During the deposition of the Lingula flags shallow-water accumulations predominated, and depression went on to the extent

[1] See Dr. Hicks, Quar. Jour. Geol. Soc., vol. xxxi. pp. 552–557.

of 4000 feet, but apparently not at a greater rate than would keep pace *pro rata* with the accumulations or deposition. This was partly due to the slow and regular depression, and partly to the increased area exposed to wave action, and the nature of the coast line.

The next depression appears to have taken place at the commencement of the *Tremadoc epoch*, and probably it was then that the western and southern parts of Russia became submerged, for we do not find any deposits in that extensive region of older date than our Arenig or Llandeilo rocks, and these rest upon pre-Cambrian or Archæan land. During the depression which extended through the Tremadoc, Arenig, and Llandeilo periods, moderately *deep water* covered the western areas, consequently deposits of a fine or muddy character predominated. In Wales, at least 4000 feet of these fine deposits occurred prior to the commencement of the known extensive volcanic action. "Stratigraphical evidence strongly favours the view that a gradual depression took place during the whole of the Cambrian and Lower Silurian epochs over the European area, and that the deposits form one complete and natural succession from the base upwards."

The evidence derived from our knowledge of the successive faunas is entirely in accordance with this view. The first fauna of which we have any knowledge is met with in those rocks occurring furthest to the west, and although the forms comprising this fauna belong to inferior classes, yet they are not the lowest types in those classes. It would appear from this *that we are far from the beginning of life* even in the earliest known Cambrian faunas, and that the species had undergone many changes previous to this period. The probable home of the earliest forms of life seems to have been somewhere towards the south-west, and possibly not far from the equator.

Conclusions and Deductions from the foregoing—

1. "That a pre-Cambrian continent extended over all the area now known as Europe, or the European area; that it probably reached considerably further to the west and north than it does at present; that the land comprising this continent had a general inclination (through sedimentation) towards the south-west; and that there was a difference of level of at least 15,000 feet between the extreme north-east and south-west.
2. "That the submergence of this continent was gradual, and that the sea encroached from the south-west.
3. "That the eastern portion of the continent did not become submerged until after the whole of the Cambrian (*Longmynd, Menevian, Lingula flags*, and *Tremadoc groups*) had been deposited over the Western areas; and that dry land continued probably to the beginning of the Devonian epoch to the more extreme eastern frontiers in Asia.
4. "That the migrations of the marine faunas were *from the south-west*, where oceanic areas prevailed.
5. "That the earliest faunas which reached the European continents indicated a lower type of organic life than those which succeeded them; and that each successive fauna seemed to indicate a higher state of progression, the lowest invertebrates appearing first, and the higher groups not until several preceding faunas had appeared." [1]

[1] Hicks, *loc cit.*, Jour. Geol. Soc., vol. xxxi.

CHAPTER III.

THE MOST ANCIENT STRATIFIED BRITISH ROCKS.

Ancient British Areas.—The most ancient Stratified Rocks in the British Islands are known at the surface in ten localities or areas, those of North and South Wales being the most extensive, and so far as they have been examined these two are the only districts composed of strata that have yielded organic remains:—

1. Anglesea,
2. Bangor and Llanberis,
3. The Lleyn Promontory,
4. The Harlech District,

(in North Wales.)

5. The headland of St. David's, or the ancient Menevia, in South Wales.
6. In Shropshire. The region termed the Longmynd, near Church Stretton.
7. A portion of the Malvern range.
8. Probably the rocks of Charnwood Forest.
9. In Ireland, only two areas, Wexford and Wicklow, exhibit at the surface rocks of this high antiquity.
10. The Western Highlands of Scotland represent the remaining region, where the Cambrian masses appear, being unconformably placed upon the fundamental gneiss of that region.

Professor Sir A. C. Ramsay, in his able memoir upon the Geology of North Wales,[1] has specially noticed six of these Cambrian districts, viz., the four in North Wales, St. David's in South Wales, and the great Longmynd Dome north-west of Church Stretton.

1. **Anglesea.**—In Anglesea the exposed rocks consist chiefly of grits, gneissic and quartz rocks, with micaceous and chloritic schists. These are highly metamorphosed Cambrian or Lower Silurian strata, all traces of life being obliterated.

2. **Bangor and Llanberris.**—The second, or Bangor and Llanberris area, is occupied by rocks differing much in character (and probably in age) from the Anglesea group, being composed of a great series of coarse and fine grits, and conglomerates, with altered green and purple chloritic slaty beds, near Bangor. Around Bethesda, Llanberris Lake, and the backs of the Ogwens, great beds of grit, with purple and green slates, occur, with here and there traces of fossils.

3. **Lleyn Promontory.**—More to the south, in the Promontory of the Lleyn[2], both gneiss and schistose rocks, highly altered, occupy the southern portion.

[1] Mem. Geol. Surv. of Great Britain, vol. iii., "Geol. of North Wales," pp. 9–13.

[2] The Welsh name of the promontory that separates Carnarvon Bay from Cardigan Bay.

4. Harlech Dome.—*The fourth region, the Harlech Dome*, is a large oval tract, which is occupied by unfossiliferous grits and purple and green slates. This grand and imposing mass holds an important position, and is significant in the physical structure of North Wales, being the site of the great Merionethshire anticlinal, on the flanks of which rest the fossiliferous flags and grits of the Lower Cambrian (Menevian and Lingula flags) series, to be hereafter noticed.

5. St. David's.—The rocks of St. David's, comprising the fifth area, are remarkable for the diversity of their characters and structure, partly resembling their equivalents in Carnarvonshire, and consisting of a great series of purple, green, grey, yellow, and brown sandstones, grits, and conglomerates, many of them fossiliferous, especially the flags and shales on the north side of St. Bride's Bay.

6. Longmynd.—*The sixth* exposure (one of the largest and most important, if not the oldest) is that of the Longmynd, a range of bold and hilly ground north-west of Church Stretton. The entire series of rocks consists of purple, brown, and olive-green slates. These are believed to be the oldest sedimentary rocks in the British Islands, and the equivalents in time of the grits, shales, sandstones, &c., below the Menevian beds of St. David's. These Longmynd and Harlech rocks at St. David's are highly metamorphosed, and are said to lie upon the so-called pre-Cambrian ridge (composed of the *Dimetian* and *Pebidian* series). This ridge strikes across the promontory from the south-west to the north-east.

7. Charnwood Forest.—The remarkable rocks of Charnwood Forest, in Leicestershire, have been assigned to rocks of Pre-Cambrian age, from the nature and character of some gneissose micaceous beds occurring at Brazilwood, near Mount Sorrel, and also from the character of the hornblendic granite of Mount Sorrel and other exposures; but the metamorphosed slates, grits, and conglomerates that lie upon and around the syenites, from their total absence of extinct life and stratigraphical position, are most probably of Longmynd age. "This old mountain-land was probably defined before the Carboniferous epoch, and constituted a scattered group of islands (archipelago) in the Triassic sea." The Cambrian rocks of some portions of the Forest (notably that of Bardon Hill area)[1] pass insensibly into Felspathic Porphyry.

8. Malvern.—The Hornblendic and Micaceous schists of Malvern, of metamorphic origin, with the granitic and trap veins, may possibly be of *pre-Cambrian* or *Laurentian* age. Cambrian grits and shales lie above them, the Hollybush Sandstone and Black Shales being the equivalents of the Lingula flags of other areas.

9. Ireland.—In Ireland, only on the east coast and on the northern part of the county of Wicklow, Howth Hill, north shore of Dublin Bay, at Brayhead, and south-east in Wexford, do these equivalent rocks make their appearance, unless much of the rock of Donegal

[1] For the latest researches into the history of the Charnwood rocks, see Quart. Jour. Geol. Soc., vols. xxxiii. xxxiv. and xxxv., "On the pre-Carboniferous Rocks of Charnwood Forest," by the Rev. E. Hill, M.A., and the Rev. Prof. T. G. Bonney, M.A.

should be of these or older ages. Dr. Kinahan has recorded from this Brayhead group the singular organism, *Oldhamia* (*O. antiqua* and *O. radiata*); also the burrows of Annelida, *Histioderma* (*H. hibernica*), with *Arenicolites didymus*, *A. sparsus*, and *Haughtonia pœcila*, and what he believed to be molluscan tracks.[1]

10. Scotland.—The tenth and last area where the oldest known masses appear, which can be assigned to the Cambrian group, occur in the north-western Highlands of Scotland, near Cape Wrath, and trend southwards along the coast as far as Applecross, where they rest upon the great mass of Archæan pre-Cambrian or Fundamental gneiss (Laurentian) of that district. The red, purple, and brown sandstones resemble those of the Longmynd and St. David's, and are of great thickness. These similar masses may be homotaxial.

Land Islands.—These ten ancient isolated masses stand out as so many *land islands, a terrestrial archipelago* (surrounded by rocks of newer and various ages), marking the sites of more deeply-seated rock-masses, now covered by newer strata. We have no trace or glimpse of the still older or pre-existing land from whence these sedimentary rocks were derived; nor do we know what was the nature of the continent, denuded or destroyed, that gave them birth. But that still older land did exist, is evident from the nature of the rocks now composing the exposed areas and masses.

CHAPTER IV.

LOWER CAMBRIAN PERIOD.

Longmynd, Llanberis, and Harlech Groups.

Cambrian (Sedgwick and Murchison).
Urschiefer-formation (Naumann).
Longmynd group and
Harlech sandstones and Llanberis slate (Wales).
Wicklow beds (Ireland).
Phyllades de Bretagne, St. Lo, &c., France.
Etage B. Schistes Azoïques ou Przibram-Schiefer.
(Barr.) Bohemia.
Regio Fucoidarum Grès à Fucoides.
Grès à Eophyton (*Angelin*) *Scandinavia.*
Huronian of Canada (*Logan*, 1850) *schists.*
Quartzites, &c. No fossils.

THE Cambrian system has received much attention both from physical geologists and palæontologists since Professor Sedgwick first studied and determined the group in great detail in North Wales. The term

[1] See G. H. Kinahan ("Manual of the Geology of Ireland," 1878) for a concise description of the Cambrian and Cambro-Silurian rocks of Ireland.

"Cambrian" was given by Sedgwick in 1831 to designate the lowest fossiliferous group of rocks visible in North Wales and the border counties.[1]

Merionethshire Anticlinal.—In the same year Sedgwick established and described the Merionethshire anticlinal, so grandly shown in the broad, wild, and rocky mountain track or irregular oval area between Barmouth and Harlech,[2] or Harlech and Dolgelly, ranging north to Maentwrog. On the west and east flanks of this oval tract the succeeding members of the Cambrian series, the *Menevian, Lingula flags*, and *Tremadoc beds* rest and are exposed.

Bangor.—The lowest beds of the Cambrian series in North Wales occur along the east side of the Menai Straits, from Bangor to south of Caernarvon, and westwards into Anglesea, where they occur as metamorphosed, gneissic, and chloritic schists, and highly crystalline quartz rocks, totally void of organic life.[3] Those east of Bangor and in the Llanberis district are altered green, purple, and chloritic slaty rocks, which stretch across the country from the banks of the Ogwen, through the Penrhyn quarries, the Lake of Llanberis, and on to Llanllyfrie or Clynog-fawr. The only fossil evidences in these rocks and those between Harlech and Barmouth are annelid tracks, which occur in the shape of burrows and trails, and are the so-called "*Chondrites*" of authors.

Longmynd.—The Lower Cambrian strata are also largely exposed in the Longmynds, a range of hills about 1600 feet above the level of

[1] THE LOWER CAMBRIAN of Sedgwick, as given in the Woodwardian catalogue, embraces the Longmynd and Harlech groups, illustrated by few but definite genera, of which Oldhamia and the Trilobites, *Conocoryphe, Paradoxides, Microdiscus*, and *Plutonia* are the chief.

THE MIDDLE CAMBRIAN of Sedgwick comprises the Menevian (Lower Lingula flags), Ffestiniog, and Tremadoc groups; the Menevian fauna is characterised by species of *Conocoryphe, Agnostus, Olenus, Paradoxides*, and *Microdiscus;* the genera, *Erinnys, Anopolenus, Holocephalina*, being essentially characteristic of the zone (*Paradoxides* and *Microdiscus* here become extinct); the Phyllopod *Hymenocaris*, with the Pteropods *Stenotheca* and *Cyrtotheca*, range no higher.

The Ffestiniog Group, or Middle and Upper Lingula flags, is represented by few Trilobites; the genus *Olenus* here attains its maximum numerical development, associated with *Dikelocephalus* (*Centropleura*).

The Lower and Upper Tremadoc groups are illustrated by new genera; *Niobe, Psilocephalus, Angelina, Asaphus, Ogygia*, and *Cheirurus*. *Conularia, Bellerophon*, and *Orthoceras* here first occur.

The Arenig or Skiddaw (Upper part of the Middle Cambrian or base of the Upper) contains for the first time many species of Graptolitidæ belonging to the genera *Graptolithus, Diplograptus, Phyllograptus, Didymograptus, Dichograptus, Tetragraptus*, and *Dendrograptus;* with species of *Calymene, Œglina*, and *Ogygia*.

THE UPPER CAMBRIAN as defined by Sedgwick comprises the Lower, Middle, and Upper Bala groups. The group *Trilobita* here attain their maximum development, accompanied by numerous *Brachiopoda*. The Tabulate and Rugose corals first appear, associated with *Protaster* and *Palæaster*, the earliest known starfishes; from here onwards in time the *Pelecypoda, Gasteropoda*, and *Cephalopoda* assume high importance.

[2] See map No. 75 of the Geological Survey.

[3] These metamorphic rocks of Anglesea have been called *Laurentian* by some authors.

the sea, N.W. of Church Stretton, in Shropshire. These rocks consist of slates, grits, conglomerates, and sandstones, which comprise the chief mass of this ancient range, and are the oldest sedimentary rocks in England or Wales. The beds strike N.N.E. and S.S.W., and rise from beneath the equivalents of the Lingula flags, and other strata which border on, and are unconformable to them, on the W. The thickness of the Longmynd group has been approximately determined to be about 23,000 feet. Their base to the E. or along the Church Stretton valley is nowhere seen.[1] The lowest beds are covered unconformably by the Wenlock and Llandovery rocks, and dip to the W.N.W. 60° to 65°. This great series, which consists of purple, red, and grey flags, sandstones, and shales with conglomerates, attains a thickness of 4000 feet in South Wales, more than 8000 in North Wales, and perhaps 25,000 feet in Shropshire (Longmynd).

It was not until 1856 that any organic remains were detected in these ancient slates, and the only fragment ascertained to exist in them was a portion of a trilobite (*Palæopyge Ramsayi*) allied to the genus *Dikelocephalus*, then the earliest form of life known in Britain. Other evidences of life are *annelid burrows*, and sinuous tracks allied to *Arenicola* (*A. didyma*). They are associated with *rain-drops*, *sun-cracks*, and *water-runnels* or *ripples*, conclusive evidence of littoral conditions. Water-worn pebbles also occur, affording additional proof of the shallow-water origin of those deposits.

St. David's.—Rocks, however, of similar character, and probably of the same age, occur at St. David's, in South Wales, and possess a more diversified fauna, indicating the presence of higher groups; no less than thirty species are known in the lowest beds, or those that underlie the Menevian group of the same area. Certain red shales and flaggy fine-grained sandstones at Castell, S. of Porth Stinian in Ramsey Sound, have yielded *Lingulella*, *Discina*, and *Leperditia*. These South Wales Cambrians are certainly *the oldest life-bearing rocks* known in Britain. Assuming the *Longmynd series* in England and Wales to be the oldest fossiliferous strata, it becomes necessary also to correlate them with strata believed to be of the same age in Ireland and Scotland.

There is much difficulty in correctly doing this from want of both palæontological and stratigraphical evidence. Great part of the Harlech and Longmynd rocks of the St. David's area and Ramsey Island is metamorphosed and highly altered. We can do no other than refer them to the same age as the "*Oldhamia*" slates of Bray Head, S. of Dublin, and Carrick Macreilly, in Wicklow, from which have been obtained the singular fossils named *Oldhamia*, *O. antiqua*, Plate I. fig. 2, and *O. radiata* (Plate I. fig. 1), and the remarkable annelid *Histioderma hibernica* (Plate I. figs. 3, 4), described by Dr. Kinahan.[2]

Until Messrs. Hicks and Salter discovered other organisms in the

[1] See sheet 36, horizontal section, of Geological Survey of Great Britain.

[2] Trans. Roy. Irish Academy, vol. xxiii. p. 547. *Ib.*, Baily, Char. Foss. and Geol. Mag. 1865.

Lower Cambrian (or Harlech and Longmynd) group at St. David's, these few forms were the only known evidence of the life of this epoch. These South Wales or St. David's rocks now yield a rich fauna, comprising 11 genera and 23 species.

The St. David's Section.—Dr. Hicks has determined the upward succession or sequence of these St. David's rocks from the "Lower Cambrian beds" to the top of the Tremadoc series.[1]

The following is the order of succession or superposition in ascending order, as seen in the fine coast-line :—

1. Greenish compact hornstones on the S.E. constitute the outermost portions of the central axis or ridge. Thickness unknown. The beds are much jointed, and dip 80° S.S.E. ; they disappear towards the W.S.W.
2. Conglomerates composed of white, red, and brown rounded quartz-pebbles, imbedded in a purple and red sandy matrix, conformable when seen to the compact quartz rocks ; the beds dip 80° S.S.E., and are about 60 feet thick.
3. Greenish flaggy sandstones, seen at Porth Clais Harbour, conformable to the conglomerate below, also seen at Caerfai and Clegyr Bridge ; about 400 feet thick.
4. Red flaggy or shaly fissile beds, resting immediately on the greenish sandstones, with the same dip, and occurring on both sides of the quartziferous ridge. Exposed in Ramsey Sound near Castell, and near Porth Clais Harbour, Nun's Chapel, and Caerfai. From these red shales have been obtained the earliest traces of life known in the St. David's promontory, if not in Britain. They are *Lingulella ferruginea* var. *ovalis*, *Discina*, sp., and *Leperditia cambrensis ;* thickness, 1000 feet.
5. Purple and greenish sandstones, coarse in texture, unfossiliferous. Exposed on the S.S.E. side of Ramsey Sound ; thickness, 1000 feet.
6. Yellowish-grey sandstone, shales, and flags. These are exposed in the headland between Porth Clais and Caer-bwdy. From this group of rocks (Plutonia beds) a remarkable crustacean fauna has been obtained, in reality the commencement of trilobite life in the Harlech series ; they are *Plutonia Sedgwickii*, *Agnostus cambrensis*, *Microdiscus sculptus*, *Paradoxides Harknessii*, *P. Hicksii*, *P. aurora*, *Conocoryphe Lyellii*, *Microdiscus punctatus*, and *Protospongia fenestrata ;* thickness about 150 feet.
7. Grey and purple sandstones and shales, containing many of the genera named above, with *Lingulella ferruginea* var. *ovalis*, *Conocoryphe solvensis*, *Paradoxides Harknessii*, *Obolella sagittalis*, *Discina pileolus*, &c. These sandstones are on the E. side of Ramsey Sound, and the N.W. side of the axis ; 1500 feet in thickness.
8. Grey flaggy grits, containing many fossils peculiar to these beds, especially *Paradoxides aurora*, *Conocoryphe bufo*, *Discina pileolus*, and *Obolella sagittalis*. These also occur in the underlying purple sandstones, and range into the Menevian group above. *Agnostus cambrensis* and *Theca antiqua* also range through these beds. *Theca penultima* first occurs here, and is limited to the Lower Menevian above.[2]

Nowhere in Europe, or elsewhere in the British Islands, does so well defined a series of Lower Cambrian rocks exist, or so prolific a fauna occur as is distributed through the 3000 feet of strata enumerated at St. David's. Until these organisms were discovered, it was believed that no fossils occurred below the Lingula flags—the Lower Cambrian

[1] Harkness and Hicks "On the Ancient Rocks of St. David's Promontory, &c.," Q. Jour. Geol. Soc., vol. xxvii. p. 384.

[2] See Harkness and Hicks, *loc. cit.*

grits and slates of North Wales and Shropshire yielding none, and being, therefore, regarded as azoic.

The St. David's Fauna.—Regarding the rocks of St. David's palæontologically, the occurrence of four large and distinct species of the genus *Paradoxides*, and the total absence of the genus *Olenus* everywhere in Wales, so characteristic of the Lower Lingula flags above, is a singular circumstance. Again, in the association of *Paradoxides* with *Agnostus*—the smallest and perhaps lowest organised trilobite known—in the same beds, we have the extremes of development, both as regards size and structural differences, meeting us at the very commencement of crustacean life.

Similar palæontological conditions occur to us when we compare these deposits with the rocks of Northern Europe and America, which occupy nearly the same horizon. The great *Paradoxides Harlani* of Massachusetts, and *P. Bennettii* of St. Mary's and Placentia Bays, Newfoundland, are types allied to those on the Menevian promontory, forming, on the whole, a group so intimately allied as to warrant our regarding the two geographical areas, now so distant, as probably once connected, or, if not contemporaneous, on the principle of homotaxis, at least as representative.[1] The primordial fauna of New Brunswick must certainly be of the same period, species of *Conocephalus*, *Paradoxides*, *Microdiscus*, and *Agnostus* being abundant.

Dr. Otto Torell has recognised in the alum shales of Sweden, in the "Regio B." of Angelin, two of the *Paradoxides* found at St. David's, viz., *P. Davidis* (Plate I. fig. 6), and *P. Hicksii*, associated with the genus *Conocoryphe*. Judging from life standard or upon palæontological grounds, certain strata or rocks along the N. side of St. Bride's Bay and Ramsey Sound may be the equivalents of the "*Fucoidal sandstone*" of Sweden, the St. David's group yielding a more extensive series of fossils. Barrande has described (from the researches of M. Casiano de Prodo)[2] numerous trilobites from representative beds in Spain, referable to the genera *Paradoxides*, *Arionellus*, *Conocephalus*, and *Agnostus*, all obtained in the province of Leon, N. of Scabero and Bonar.

Ireland.—The purple and green Cambrian slaty schists of Bray Head, co. Wicklow, and Wexford, appear to be of the same age as the purple, grey, red, and yellow sandstones, &c., of St. David's, although no species is known to occur in common, the entire absence of *Crustacea*, *Amorphozoa*, and *Brachiopoda* being remarkable. The only organisms known in these ancient rocks are *Annelida* and *Hydrozoa*. The former group contains the singular genus *Histioderma* (*H. hibernica*), *annelid tracks*, and two species of *Hydrozoa*, named by Professor Edward Forbes *Oldhamia radiata* and *O. antiqua*, after their discoverer, Dr. Oldham. They appear to strongly resemble

[1] *Paradoxides* is represented in America by six species, while England, Scandinavia, Bohemia, Spain, and France have yielded twenty species, all of which occur in the lowest portion of the Cambrian rocks, none ranging higher than the Lingula flags.

[2] Bull. Soc. Géol. France, 1860, vol. xvii. p. 516 *et seq.*

certain forms of Sertularidæ; they also resemble the lime-secreting Algæ or Calcyphyte, *Corallina officinalis*. It is probable that Oldhamia may belong to the calcareous Algæ, rather than to the Hydrozoa.[1] (Consult G. H. Kinahan's "Geology of Ireland," where all connected with these ancient rocks is ably described.)

Dr. Hicks has proposed the following division for the Cambrian rocks at St. David's, which are clearly separable into three series in ascending order, viz., the *Caerfai*, *Solva*, and *Menevian* groups.

1. CAERFAI.—The Caerfai group consists of conglomerates and sandstones, with red and purple and green slates and shales. In red slates near the base have been obtained *Lingulella*, *Discina*, and *Leperditia*, and abundant traces of annelids.

Beds of the same age also occur in the Harlech mountains.

The great Penrhyn or Bethesda and Llanberis slate quarries in Caernarvonshire are also on this same horizon. It is possible again that the thick conglomerates which rest on the Eozoic (Archæan) rocks along the N.W. coast of Scotland may be of Lower Cambrian age, and contemporaneous with those of St. David's. The St. David's rocks are subdivided into the three following groups:—

Caerfai group .	Upper, 1000 feet	Purple sandstones with *Annelids*.
	Middle, 50 feet	Red shales and schists, with *Leperditia cambrensis*, *Lingulella primæva*, *Discina caerfaiensis*, &c.
	Lower, 520 feet	Conglomerates and greenish flaggy sandstones, with *Annelids* and *Fucoids*.

2. SOLVA GROUP.—The lowest beds of this division are yellowish sandstones and grey flags, which contain a crustacean fauna, comprising the genera *Plutonia*, *Paradoxides*, *Conocoryphe*, and *Microdiscus*; also *Lingulella*, *Theca*, and *Protospongia*. The middle part of the Solva group consists of red, purple, and grey sandstones and slates of great thickness (1800 feet); towards the upper part of this series *Paradoxides*, *Conocoryphe*, and fragments of other organisms occur. The Solva group may represent the main portion of the Harlech grit series in Merionethshire. They are thus divided by Dr. Hicks:—

Solva group .	Upper, 150 feet	Grey rocks, with *Paradoxides aurora*.
	Middle, 1500 feet	Grey, purple, and red rocks, with *Paradoxides solvensis* and *Conocoryphe solvensis*.
	Lower, 150 feet	Yellowish grits, sandstones, and flags, with *Paradoxides Harknessii*, *Plutonia Sedgwickii*, with *Eophyton?* and *Fucoids*, &c.

The following extended table, prepared by Dr. Hicks, gives the position and relation of these groups to those above and their systematic place, from the Bala or Ordovian group to the base of the Lower Cambrian:—

[1] The fresh-water algoid genus *Batrachospermum* resembles in a marked manner the radiating clusters in *Oldhamia antiqua*.

TABLE IV.—CAMBRIAN PORTION OF THE BRITISH LOWER PALÆOZOIC STRATA, BY DR. HICKS.

		Groups.	Petrological Characters.	Thickness of Strata.	Characteristic Types and Order of Appearance of Life.	Localities where Exposed.
				Feet.		
Upper Cambrian.	Ordovian[1] (Lapworth).	Bala Group	Sandstones, Flags, Shales, and Limestone	4000 to 12,000	. . . . .	Bala, Caradoc Ridge, Horderly, Norbury, Snowdon, Haverfordwest, Wexford, Kildare, Hartfell.
		Llandeilo Group	Calcareous Shales, Flags, and Sandstones	3000	Actinozoa	Dumfriesshire, Llandeilo, Builth, Abereiddy Bay, &c.
		Llanvirn Group	Grey Flags and Black Slates	2000	. . . . .	Llanvirn and Coast of Abereiddy Bay, Ramsey Island, Shelve, &c.
		Arenig Group	Slates, Flags, and Sandstones	2500	Gasteropoda . . . . . Echinodermata (*Crinoidea, Asteroidea*).	Arenig, Shelve, Ramsey Island, and Whitesand Bay (St. David's), Skiddaw (Cumberland).
Middle Cambrian.	Upper Cambrian.	Tremadoc Group	Dark Slates and Flaggy Sandstones	1000	Hydrozoa (*Graptolites*). Lamellibranchiata and Cephalopoda .	Portmadoc, Ramsey Island, and Whitesand Bay (St. David's), Shineton (Shropshire).
		Dolgelly Group	Soft Black Slates and Shales	600	Bryozoa (*Dictyonema*) . .	Portmadoc, Dolgelly, Malvern, Whitesand Bay, &c.
		Ffestiniog Group	Grey Arenaceous and Micaceous Flags	2000	Heteropoda, Plantæ (marine plants?).	Maentwrog, Dolgelly, Malvern, Ramsey Island, Solva.
		Maentwrog Group	Slates, Flags, and Sandstones	2500	Crustacea (*Phyllopoda*) . .	Maentwrog, Dolgelly, Solva.
Lower Cambrian.	Lower Cambrian.	Menevian Group	Dark Slates and Flags	750	Echinodermata (*Cystidea*) . . Pteropoda.	St. David's, Solva, Maentwrog, Dolgelly.
		Solva Group	Purple, Red, and Grey Grits, Flags, and Slates	1800	Crustacea (*Ostracoda, Trilobita*) .	Solva, St. David's, Harlech Mountains, Longmynd Range, Bray Head, &c.
		Caerfai Group	Purple, Green, and Red Sandstones and Slates, Conglomerates.	1600 to 4000	Brachiopoda, Protozoa, Annelida	St. David's, Whitesand Bay, Bangor, Llanberis, &c.

[1] The name Ordovian is proposed by Professor Lapworth to receive the group of the Arenig, Bala, and Llandeilo rocks.

The groups comprise the *Cambrian* of Professor Sedgwick.

CHAPTER V.

PALÆONTOLOGY OF THE LOWEST CAMBRIAN ROCKS.

THE general absence of limestones from the Cambrian rocks is necessarily followed by the absence also of the *Rhizopoda* or *Foraminifera*, the *Actinozoa* or Corals, and other life groups which we commonly find in calcareous strata, and which abound in the middle and upper part of the succeeding Silurian. The character and nature of the sea-bottom, whether arenaceous, argillaceous, or calcareous, must have determined, as it does now, the distribution of life over the floor of the Cambrian sea. The circumstance that we have not a richer fauna is due, undoubtedly, to want of preservation of organisms which were actually entombed at the time of deposition.

We know of the occurrence in these lowest Cambrians, comprising the Longmynd, Harlech, and Llanberis rocks of North and South Wales, of 18 genera and 32 species; 8 of the former and 12 of the latter passed up into the succeeding Menevian strata.

Probably the great groups of rocks comprised under the name Archæan of Dana, Laurentian and Huronian, may be the equivalents in time of our Scotch, St. David's, and North Wales Pre-Cambrian; and his Primordial or Cambrian system (embracing the two series Acadian and Potsdam) may represent the lower portion of our fossiliferous Cambrian rocks, or those developed at St. David's, viz., (1) the red shales and flaggy beds with *Lingulella ferruginea* and *L. primæva;* (2) the red, purple, and grey grits; (3) the *Plutonia* beds; (4) the red, grey, and purple flaggy sandstones; and (5) the succeeding grey flaggy series, all five of which are fossiliferous.

Contrast of the Lower Cambrian Areas.—These Pembrokeshire Cambrian rocks seem to have no precise equivalents in North Wales, unless they represent in time the Llanberis, Harlech, and Bangor sandstones, grits, and flags, which, however, have as yet yielded no trace of organic remains. Very few species are common to these sandstones and the succeeding Menevian group, which has yielded nearly fifty species;[1] yet in the Harlech, Barmouth, and Dolgelly areas the Menevians immediately succeed and are conformable to the underlying barren unfossiliferous grits, and exhibit the first traces in North Wales of a definite fauna. In other words, the supposed representatives of the Harlech and Llanberis beds, in the St. David's promontory, contain a well-marked fauna, highly characterised by the Crustacea, and by the more important fact that no species occurring in the rocks of St. David's are known in North Wales. It is only with the succeeding Menevian (Lowest Lingula flags) that a well-marked community of life occurs. Of the 12 Pembroke-

[1] The Middle Cambrian or Lower Lingula flags of Sedgwick, the Lingula flags of authors, and the Upper Cambrian of Lyell and Salter, and the Menevian group of Salter and Hicks.

shire Lower Cambrian species (9 of which are Trilobita, viz., *Agnostus cambrensis, Conocoryphe bufo, C. Lyellii, C. solvensis, Microdiscus sculptus, Paradoxides aurora, P. solvensis, P. Harknessii,* and *Plutonia Sedgwickii*) not one is known out of that area; whereas of the 28 Menevian species known in the same area, 12 are common to it and North Wales, while 3 other trilobites are confined to North Wales, viz., *Agnostus reticulatus,* Ang., *Conocoryphe coronata,* and *C. Homfrayi.*

This non-occurrence of fossil remains other than annelid burrows (*Chondrites* and *Cruziana*) in the Cambrian of the Geological Survey, has much significance when they are compared with groups of rocks equivalent in time, and not far removed geographically, where metamorphism has not affected their original condition so as to obliterate all traces of life. The physical sequence in both North and South Wales is the same, as determined by the position of the Menevian beds, which in South Wales have a fossiliferous base in the purple sandstones; while the Menevian beds of North Wales (so far as is at present known) rest on the unfossiliferous Bangor, Llanberis, and Harlech grits, throughout their known appearance and range.

Harlech and Longmynd Fauna.—(1) The fossils which occur in the lowest known part of the Harlech and Bangor group at St. David's are *Lingulella ferruginea, L. primæva, Discina,* sp., *D. caerfaiensis,* and *Leperditia cambrensis;* these all occur in the lowest red shales below the sandstone at Castell, on the east side of Ramsey Sound.

(2) About 1000 feet of unfossiliferous grits and sandstones succeed this first known fossiliferous group.

(3) In yellowish-grey flaggy sandstones, between Porth Clais Harbour and Caerbuddy, we meet for the first time, as before mentioned, with the gigantic Crustacea (Trilobita) *Plutonia* and *Paradoxides,* associated with two genera, *Microdiscus* and *Agnostus,* almost microscopic in size.

In the same beds are Protozoa belonging to two species of Hexactinellid sponges, *Protospongia fenestrata* (Salt.) and *P. major* (Hicks). Two species of Pteropoda, *Theca antiqua* (Hicks) and *T. penultima* (Salt.), also occur. This first assemblage of life, so far as we know, the *earliest in the earth's history,* consists of forms whose organisation is *not* embryonic, and distinctly points to a line of ancestors belonging to this or some other area yet to be discovered. The entire fauna of these *Plutonia* beds consists of 8 genera and 9 species, 5 of which are Trilobita (viz., *Plutonia Sedgwickii, Paradoxides Harknessii, Conocoryphe Lyellii, Microdiscus sculptus,* and *Agnostus cambrensis*), with *Protospongia fenestrata, P. major, Lingulella ferruginea,* and *Theca antiqua;* three of these, *Lingulella ferruginea, Agnostus cambrensis,* and *Protospongia fenestrata,* pass to the Menevian group. *Plutonia Sedgwickii, Conocoryphe Lyellii,* and *Microdiscus sculptus* have not been detected in any higher horizon, and *P. Harknessii* only in the succeeding flaggy sandstones, where it is associated with *Conocoryphe solvensis,* which represents *Conocoryphe*

Lyellii below. Grey and purple sandstones, 1500 feet thick, but with a scanty fauna of only five species, succeed the *Plutonia* sandstones. Finally, the Harlech and Llanberris group at St. David's terminates with grey sandstones, which contain another form of *Paradoxides* (*P. aurora*), *Conocoryphe bufo*, and *Agnostus cambrensis;* in all, 8 species occur.

Numerically the fauna of the whole Lower Cambrian comprises 68 genera and 185 species, ranging from the lowest red shales to the top of the Upper Tremadoc. The Harlech beds yield 18 genera and 31 species, the Menevian group of South Wales 23 genera and 52 species, the Lower Lingula flags of all localities 17 genera and 37 species, the Upper Lingula flags 13 genera and 37 species, the Lower Tremadoc 31 genera and 60 species, and the Upper Tremadoc 20 genera and 33 species. Of this Lower Cambrian fauna (68 genera and 185 species) only 12 genera and 16 species pass to the Arenig; of these, 5 are Trilobita, *Asaphus affinis*, *A. Homfrayi*, *Cheirurus Frederici*, *Dionide atra*, and *Ogygia scutatrix*. It will be observed that these are all Tremadoc species, none of the Longmynd, Menevian, and Lingula flag forms ever appearing above the Lingula flags.

The species of Brachiopoda, *Lingulella primæva*, *L. ferruginea* var. *ovalis*, and *Obolella maculata*, do not pass out of the lowest divisions; while *Lingula petalon*, *L. lepsis*, *Lingulella Davisii*, *Obolella plicata*, and *Orthis Carausii*, *O. lenticularis*, and *O. menapiæ* unite the Tremadoc to the Arenig. The remaining Mollusca are pelagic. No Gasteropoda occur, and no form of Pelecypoda until we reach the Lower Tremadoc, where 12 species first appear, showing this earliest-known fauna to have been highly specialised and of long duration. The large crustacean fauna numbers 34 genera and 110 species, only 5 of which passed to the Arenig; none of the great Olenidæ (*Paradoxides*, *Plutonia*, and *Neseuretus*) pass to the higher division of the Cambrian or Cambro-Silurian rocks.

The Pelagic fauna, as exemplified by the Pteropoda and Heteropoda, is the largest known (5 genera and 21 species), including *Cyrtotheca*, 1 species; *Theca*, 13; *Stenotheca*, 1; *Conularia*, 1; and *Bellerophon*, 5. Nine of these are St. David's forms, and only *Theca simplex*, *Conularia Homfrayi*, and *Bellerophon multistriatus* pass to the Arenig.

Plantæ.—Granting that the *Oldhamiæ* might be calciphytes or calcareous corallines, resembling in habit the *Melobesiæ* and *Nulliporæ* of modern seas, or the group of so-called corallines, so abundant in the seas of warmer latitudes, we are still at a loss as to their true nature. Göppert refers them to sea-weeds, and compares *O. antiqua* with the living *Liagora ramellosa* of Kützing from Teneriffe; but Göppert makes two genera of *Oldhamia*, *Murchisonites* and *Oldhamia*, the *O. antiqua* of Forbes being his *Murchisonites antiqua*. Professors Kinahan and Edward Forbes both referred them to the class Hydrozoa, as having affinities with the Sertularidæ[1] (see Plate I. figs. 1, 2).

[1] *Vide* Baily, "Figures of Characteristic Brit. Foss.," vol. i. Palæozoic, p. 1, t. 1 (1875). This book should be in the possession of all students of Palæozoic palæontology.

*

No traces whatever of these singular remains have been found in any of the Cambrian rocks out of Ireland. Possibly their place is amongst the Hydrozoa. It is singular that, amidst these grandly developed and similar rocks of North and South Wales, no trace of these doubtful forms have occurred.[1]

Protozoa.—Four species of Hexactinellid sponges, by no means uncommon in the Longmynd and Menevian rocks, occur at St. David's. Three of the four species belong to the Harlech beds, and all four occur in the Menevian. *Protospongia fenestrata* also occurs in the Lower Lingula flags proper. Zittel places these sponges in the family Euretidæ with the Hexactinellidæ, and in the group Dictyonina. The original form of these sponges we know not; they may have been flat and incrusting, or "sacciform," and anchored in the slimy ooze of the sea-bottom by a tuft of anchoring spicules.[2] The spiculæ were originally siliceous, but are now converted into iron pyrites. The fact also that the spiculæ are separate, not being "enveloped in a common coating or united by ankylosis, clearly places or assigns them to the group Lyssakina of Zittel, nearly equivalent to Mr. Carter's division of the Sarco-hexactinellidæ." The species known are *Protospongia diffusa* (Salt.), *P. fenestrata* (Salt.), *P. major* (Hicks), and *P. flabellata* (Hicks). No traces of these sponges have occurred either in the Harlech, Longmynd, Menevian, or Lingula flags of North Wales. They may be sought for round the Harlech Dome, amidst the black shales and flags of the Menevian beds.

Echinodermata.—No form is known below the Menevian beds, in which occurs the cystidean *Protocystites menevensis* (Hicks).

Annelida.—The Longmynd group yields 4 genera and 5 species, *Arenicolites uricomiensis*, *A. sparsus*, *Scolites socialis?*, *Haughtonia pœcila*, and *Histioderma hibernica*. If the quartzites of the Wrekin in Shropshire are of the age assigned to them, then the *Arenicolites uricomiensis* is the oldest *British* fossil, and with the exception of *Eozoon canadense*, the oldest known fossil. Beyond the doubtful Annelidan tracks, and one species, *Arenicolites sparsus*, from the Longmynd rocks, we have no determined species. Two of the known five species (*Haughtonia pœcila* and *Histioderma hibernica*) are Irish, from near Bray Point. Nine out of ten of the so-called fucoidal or plant-remains in the rocks below the Devonian, are only Annelid burrows.[3]

Hydrozoa.—None are known below the Upper Lingula flags, or the Lower Tremadoc.

Crustacea.—The most abundantly preserved forms of life in the Lower Cambrian rocks are the Crustacea, and chiefly of the extinct order, *trilobita*. No less than 7 genera and 13 species

[1] That the seas of the Cambrian period possessed their marine algæ can hardly be doubted; but the so-called *Eophyton* of the Swedish Cambrians are undoubtedly annelid tracks.

[2] See Quart. Jour. Geol. Soc., vol. xxxvi. pp. 362–367, Sollas "On the Structure and Affinities of the Genus *Protospongia*."

[3] The term "Fucoids" will have to be modified, or all but expunged, from our nomenclature.

occur in the lowest Cambrian or Harlech rocks of St. David's, 10 of which are confined to them; the remaining 3 species (*Agnostus cambrensis*, *Conocoryphe bufo*, and *Paradoxides aurora*) connect the Harlech and Longmynd Crustacea with the Menevian. The 7 genera are *Agnostus*, *Conocoryphe*, *Leperditia*, *Microdiscus*, *Paradoxides*, *Plutonia*, and *Palæopyge*: *Conocoryphe Lyellii* and *C. solvensis*, 3 species of *Leperditia* (*L. ferruginea*, *L. cambrensis*, and *L. primæva*), *Microdiscus sculptus*, and *Plutonia Sedgwicki* are all confined to the Harlech group of St. David's. The Crustacean fauna known in the six divisions of the Lower Cambrian rocks, and up to the close of the Upper Tremadoc, comprises 103 species. The Menevian group possesses the largest known Crustacean fauna, and, except the Brachiopoda, in the largest numbers. These Trilobites appear at once in these strata in their full structural development, and are of dimensions never afterwards equalled, many individuals of the species *Paradoxides Davidis* (Plate I. fig. 6) being nearly two feet long. With these are associated the smallest known forms, said to be embryonic. "Dr. Hicks has shown that while certain genera (*Paradoxides* and *Plutonia*) had attained their full or maximum size in Cambrian times, they were accompanied by genera showing or exhibiting every stage of development, from the little *Agnostus* with two thoracic somites, and *Microdiscus* with four, to *Erinnys* with twenty-four," while blind genera occur together with those having the largest eyes.[1]

Brachiopoda.—Only 6 species are essentially Harlech forms, *Discina pileolus*, *D. caerfaiensis*, *Lingulella ferruginea* and var. *ovalis*, *L. primæva*, and *Obolella sagittalis*. Five genera and 20 species range through the six lowest horizons, or from the Longmynd group to the Upper Tremadoc; but only the six species named occur in the lowest Cambrian beds.

Pelecypoda (Lamellibranchiata).—No bivalve shell is known to occur below the Lower Tremadoc. For the first time in Britain we there recognise 5 genera with 12 species. *Davidia* and *Glyptarca* are new; the remaining 3 are the well-known genera, *Modiolopsis*, *Palæarca*, and *Ctenodonta*. This is the first known appearance of the Pelecypoda in time in any region.

Gasteropoda.—None are known below the Arenig, where 4 genera occur, both in South Wales (St. David's) and in the Stiper-stones area.

Pteropoda.—The Lower Cambrian yield 4 genera, *Cyrtotheca*, *Stenotheca*, *Theca*, and *Conularia*, which are represented through the six stratigraphical divisions by 11 species; but only 2 occur in the Longmynd group of St. David's (*Theca antiqua* and *T. penultima*). The Menevian beds of the same area have yielded 6 species, and the Lower and Upper Tremadoc 9 species.

Heteropoda.—*Bellerophon* is the only form that occurs in these lowest rocks; but no species has been recorded lower than in the so-called Middle Lingula flags, where, as *B. cambrensis*, the genus first appears, associated with *Hymenocaris vermicauda* (Plate I. fig. 5), and *Conocoryphe* in the Upper Ffestiniog rocks. Four of the five known

[1] Quart. Jour. Geol. Soc., vol. xxviii. p. 174.

species are Tremadoc, where the genus becomes specifically of importance.

Cephalopoda.—No species known until we reach the horizon of the Tremadoc rocks, where for the first time we find both *Cyrtoceras* and *Orthoceras* in Britain.

Palæontological Summary.—We have thus seen how unequally distributed (as we should expect) are the zoological groups through the lowest Cambrian rocks, and how distinctively certain genera characterise them, and, as will be found on analysis of the Menevian, Lingula flags, and Tremadoc life, we learn how distinct a period is represented by all below and up to the close of the Tremadoc age. The six divisions of the Lower Cambrian represent the earliest history of the British rocks; for out of the 61 genera and 182 species known to range through them, only 11 genera and 16 species pass to the Arenig rocks.

The Cambrian, if we take Palæontological evidence as a guide to classification, may be divided according to the distribution of characteristic Trilobites into two series. The lowest Cambrian, Harlech, Longmynd, and Menevian groups may be fairly termed *Paradoxidian*, and the Upper, Lingula, and Tremadoc, *Olenidian*.

The Brachiopoda, illustrated by *Lingulella* and *Discina*, which first appeared and are so characteristic of these ancient rocks, have lived on (generically) with but little change through all geological time, *Lingula still living* in the eastern seas, and *Discina* near our own shores. In the Harlech and Longmynd group *no Pelecypoda, Gasteropoda, Heteropoda*, or *Cephalopoda* are known. The same classes are unknown in the Menevian and Lingula flags. No Gasteropoda or Cephalopoda occur on the Lower Tremadoc, and no Pelecypod or Gasteropod have yet been detected in the Upper Tremadoc. The Pelagic *Pteropoda* is represented in the Harlech series by 2 species, the Menevian by 3 genera and 6 species, and in the Lower Lingula flags by 2 species. The *Heteropoda* appear for the *first time* in the Lower Tremadoc as *Bellerophon ramseyensis, B. solvensis*, and *B. shinetonensis*.

CHAPTER VI.

MENEVIAN GROUP.[1]

Menevian group, Salter and Hicks, 1865.
Lower Lingula flags with Paradoxides. (Auct.)
Grès poripres, ou Greywacke lie de Vin de Bretagne. (France).
Etage C. Schistes protozoiques de Ginetz. (Barrande) *Bohemia.*
Regio B. Conocorypharum d'Angelin, Schistes Alunifères inférieurs. (Angelin) *Scandinavia.*
Paradoxides beds and Taconic System. (America.)

THE name "Menavian" was established to distinguish a group of certain strata in the St. David's promontory, in Pembroke-

[1] Menævia is the classic or Roman name for St. David's.

[illegible]

[illegible]

1. [illegible]
2. [illegible]
3. [illegible]
4. [illegible]
5. [illegible]
6. [illegible]
7. [illegible]
8. [illegible]

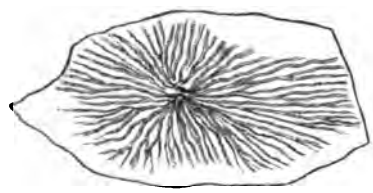
PLATE I.

CAMBRIAN FOSSILS.

1. *Oldhamia radiata.* Lowest Cambrian, Bray Head, Wexford, Ireland.
2. *Oldhamia antiqua.* Lowest Cambrian, Bray Head, Wexford, Ireland.
3. *Histioderma Hibernica* (Kinn.) Lowest Cambrian, Bray Head, Wexford.
4. *Histioderma Hibernica* (Kinn.) Showing fine transverse lines.
5. *Hymenocaris Vermicauda* (Salt.) Lingula flags, North Wales.
6. *Paradoxides Davidis* (Salt.) Menevian and Lingula flags, South Wales.
7. *Olenus micrurus* (Salt.) Lingula flags.
8. *Lingulella Davisii* (M'Coy). Lingula flags, Tremadoc, and Arenig.

PLATE I.

CAMBRIAN FOSSILS.



1

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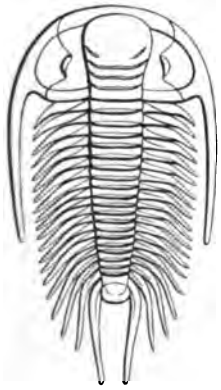

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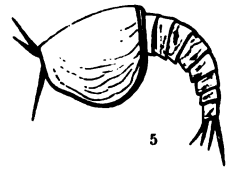

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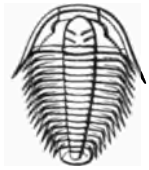

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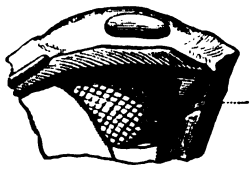

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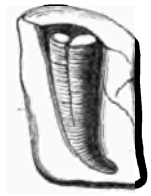

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shire,[1] which contains an important fauna; these rocks constitute the lowest division of the Middle Cambrian of Sedgwick, being equivalent to his Lower Lingula flags, and are embraced in the Lingula flags of most authors. They are also the equivalent to Barrande's Etage C. in Bohemia, where the Trilobita *Paradoxides*, *Conocoryphe*, and *Agnostus* occur, but no true *Oleni*. *Erinnys* and *Holocephalina* are essentially South Wales forms. The Menevian occurs in Sweden, has been recognised in North America and Canada, and in the St. John's group in Newfoundland.

Stratigraphical Relations of the Menevian Beds.—The Menevian is now recognised as a separate Palæontological division, distinguished from the Lingula flags proper above, just as the Ffestiniog of Sedgwick was applied to the Middle and Upper groups of the Lingula flags in North Wales. In South Wales the Menevian series is about 700 feet thick, more or less fossiliferous throughout, and contains a fauna numbering 24 genera and 52 species.

Probably the base of the Menevian cannot be separated from the underlying grits and sandstones of the Harlech and Bangor series, passing as they do insensibly, both in North and South Wales, into them, and also into the true Lingula flags above.

The Menevian of St. David's is the most typical both as regards physical development and the abundance of organic remains. The intricacy of the geological structure of North Wales renders both the mapping and the collecting of fossils in the Menevians far more difficult than in the St. David's promontory, the strike of the beds being more disturbed in continuity; we doubt not, however, that an extensive fauna is yet to be obtained from the Menevian of North Wales, where the typical Lower Lingula flags mantle round the still older Cambrian masses. In North Wales the Menevian beds are confined to the southern, eastern, and northern sides of the Merionethshire anticlinal, resting upon the Harlech rocks comprising this great mass of county. They are well exposed between Dolgoed on the Mawddach, and the district of Trawsfynydd, also north of Tafarnhelig, at the northern apex of the anticlinal, where they occupy a considerable area on strike. The thickness of the Menevians in North Wales seldom exceeds 700 feet. The Menevian group is divided into the three following sections:—

Menevian Group.	Upper, 100 ft.	Sandstone and Shales, with *Orthis Hicksii*, &c.
	Middle, 350 ft.	Flags and Slates, with *Paradoxides Davidis*, &c.
	Lower 300 ft.	Grey Flags, with *Paradoxides Hicksii*, &c.

Menevian Trilobites.—The Menevian series at St. David's rests upon and passes insensibly down into the fossiliferous Harlech and Bangor series, which contain an earlier fauna, not represented in

[1] First announced at the British Association, Birmingham, 1865, "Report," p. 281, by Messrs. Salter and Hicks.

North Wales, either at Harlech or Bangor. Only one of the 5 species of the great *Paradoxides* found in the pre-Menevian and Menevian beds of South Wales is known in North Wales. Associated with these large *Paradoxides*, other forms equally significant occur, viz., *Holocephalina inflata*, *H. primordialis*, and *Carausia menevensis;* they range no higher, being distinctively characteristic species of this horizon. Two species of *Anopolenus* (*A. Henrici* and *A. impar*) are common to the two areas, the former occurring at Rhaidr-ddu valley, Tyddyngwladis, near Dolgelly, the latter at the Maentwrog Waterfall. Six species of the genus *Conocoryphe* occur in the Menevian group: 3 characterise the St. David's, and 2 the North Wales beds; and one species, *C. applanata*, is common to both areas. *Conocoryphe humerosa*, *C. bufo*, *C. solvensis*, are found at St. David's only; *C. coronata*, *C. Homfrayi*, occur in North Wales, at Maentwrog; *C. applanata* unite the two areas. *Erinnys venulosa* and *Arionellus longicephalus* are both found in the Waterfall valley at Maentwrog, and at St. David's. We draw attention to this group of Crustacea because they are stratigraphically important, and constitute by far the most characteristic portion of the fauna of the lowest Cambrian rocks.

No less than 9 genera and 26 species of Trilobita occur in the Menevian rocks of North and South Wales, or, in other words, more than half the known fauna is Trilobitic. In these beds occur the first known Cystidean (Protocystites), associated with Pteropoda (*Theca*) and Entomostraca.[1] The finding *Paradoxides Davidis* and *P. Hicksii* at Dolgelly, on the same horizon as that of St. David's, immediately above the Lower Cambrian sandstones (Harlech and Barmouth beds), in bands of uncleaved Menevian slate and ashes, aids greatly in the correlation of the two areas.

Genera which first appear in the Menevian Beds.—We may mention the following genera which first appear in the Menevian beds:—

Cystidea	*Protocystites.*	Crustacea	*Carausia.*
Annelida	*Arenicolites.*	„	*Primitia.*
„	*Serpulites.*	„	*Leperditia.*
Crustacea	*Arionellus.*	Brachiopoda	*Orthis.*
„	*Anopolenus.*	„	*Obolella.*
„	*Erinnys.*	Pteropoda	*Cyrtotheca.*
„	*Entomis.*	„	*Stenotheca.*
„	*Holocephalina.*		

The absence of the genus *Olenus* (Plate I. fig. 7) in the Menevian and Lingula flags or primordial rocks of St. David's is singular. The genus is abundantly represented both in the Lower and Upper Lingula flags of North Wales, where no less than 12 species are known, 4 in the lower division and 8 in the upper; and 4 distinct forms (viz., *O. bisculcatus*, *O. scarabæoides*, *O. humilis*, and *O. pauper*) occur in the Upper Lingula flags of Malvern, over-

[1] Harkness and Hicks, Quart. Jour. Geol. Soc. vol. xxxi., "On the Ancient Rocks of St. David's Promontory and their Fossil Contents."

lying the Hollybush sandstones. *Olenus scarabæoides* (*Olenus spinulosus*, Phill.) is found also in the Upper Lingula flags of Carreg-Wen, west of Portmadoc. *Olenus* is essentially an Upper Lingula flag genus; and none pass out of the Lower Cambrian rocks or above the Tremadoc group, where 4 species occur (*O. alatus*, *O. impar*, *O. triarthrus*, and *O. Salteri*).

Foreign Representatives of the Menevian Fauna.—Comparison of the earliest known faunas in Europe and America with that of St. David's shows conclusively that they are identical as to age or time of deposition, and in genera also. This Angelin has demonstrated through his researches into the alum shale of Sweden; and the primordial fauna of Barrande has yielded *Paradoxides*, *Conocoryphe*, *Agnostus*, and *Ellipsocephalus*, the first three of which are characteristic British genera.

Sweden has yielded *P. Hicksii* and other forms like our own.

The Spanish primordial rocks contain genera identical with those of our Menevian and Lingula-flags—*Paradoxides*, *Conocoryphe*, *Arionellus*, and *Agnostus*. The Protozoic schists of Bohemia (Region C, Barrande) also yields *Paradoxides* (*P. bohemicus*), *Sao*, *Conocoryphe*, and *Agnostus*. America, in its Acadian group, contains *Paradoxides*, &c. The same conditions prevail in Canada and New Brunswick. It would thus appear that all the regions in Europe and America north of 30° of latitude to the polar regions, contain these primordial rocks and fossils.

Palæontology of the Menevian Beds.

Protozoa.—The St. David's beds of this age contain all the known species of *Protospongia*, viz., *P. diffusa*, *P. fenestrata*, *P. major*, and *P. flabellata*, the first three of which, as we have seen, are also Longmynd and Harlech forms. At St. David's *P. fenestrata* passes up to the Lower Lingula flags proper. No sponges have occurred either in the Menevian beds or Lingula flags of North Wales.

Echinodermata.—Cystidean remains occur at St. David's, and have received the name *Protocystites menevensis*.

Annelida.—*Arenicolites didymus*, *A. sparsus*, and *Serpulites fistula*, appear to be all that are known of the Anarthropoda in the Menevian beds. The first two are confined to this horizon; *S. fistula* passes to the Upper Lingula flags.

Crustacea.—The largest crustacean fauna of the six divisions of the lowest Cambrian rocks occurs here. Twelve genera and 32 species characterise the Menevians of North and South Wales. *Agnostus* is represented by 7 species, *Anopolenus* 3, *Conocoryphe* 7, *Paradoxides* 3, *Holocephalina* 2, and *Leperditia* 4 species. These 6 genera are the chief and most largely represented. *Arionellus*, *Erinnys*, *Microdiscus*, and *Carausia*, each with 1 species, are all confined to the Menevian beds, and generically characterise them. The black slaty flags of St. David's yield the gigantic *Paradoxides P. aurora*, *P. Davidis*, and *P. Hicksii*; this last-named species has been

recorded from the Lingula flags of North Wales under the name *P. Forchhammeri*. The Menevian beds are connected with the Harlech and the Longmynd group below through 3 species, viz., *Agnostus cambrensis*, *Conocoryphe bufo*, *Paradoxides aurora*. No *Oleni* are known in the Menevian rocks, although 13 species occur in the Lingula flags proper.

The genera *Paradoxides* and *Erinnys* surprise us by their highly-developed structure and size, and enable us to assume the pre-existence of prior faunas from which these were derived. The abundance of individual life is proved by the presence of phosphates in these rocks. Dr. Hicks has shown that those rocks which abound in crustacean remains, invariably possess the largest amount of phosphoric acid.[1]

Polyzoa.—No remains of this class occur in the Menevian; they first appear in the Upper Lingula flags under the form of *Dictyonema?*

Brachiopoda.—Only 4 genera and 6 species range through the Menevian beds, *Orthis Hicksii* being the only peculiar form. *Lingula ferruginea*, and var. *ovalis*, *Obolella maculata*, *O. sagittalis*, and *Discina pileolus* (Salt.), are associated either with the Harlech beds below or the Lower Lingula beds above. Every species occurs in the St. David's Menevian beds. It is not until we rise into the Llandeilo and Caradoc rocks that the class becomes (numerically) so important a factor in the Cambrian and Silurian rocks.

Pteropoda.—*Cyrtotheca hamula*, *Stenotheca cornucopia*, *Theca corrugata*, *T. penultima*, *T. menevensis*, and *T. stiletto*, are known. Four of the 6 species, viz., *C. hamula*, *S. cornucopia*, *T. menevensis*, and *T. stiletto*, are Menevian only. *T. corrugata* is the only form that passes to the Lower Lingula flags above.

Palæontological Summary.—Thus out of the 52 species constituting the fauna of the Menevian rocks, 32 are Crustacea, viz., *Agnostus*, 7 species; *Conocoryphe*, 7; *Paradoxides*, 3; *Anopolenus*, 3; *Holocephalina*, 3; *Leperditia*, 4; *Entomis*, *Microdiscus*, and *Arionellus*, 1 species in each. The only other classes fairly represented are the Brachiopoda and the Pteropoda, 6 species in each. A marked feature is the first appearance of Cystidea (*Protocystites*) and Crinoidea (*Dendrocrinus*). Eight whole classes are entirely unrepresented: the Plantæ, Hydrozoa, Actinozoa, Polyzoa, Pelecypoda, Gasteropoda, Heteropoda, and Cephalopoda being all absent.

Of the 32 species occurring in the Lower Cambrian (Longmynd and Harlech), 10 are common to or unite the two groups. They are: *Protospongia*, *Paradoxides aurora*, *Conocoryphe applanata*, *Conocoryphe bufo*, *Conocoryphe humerosa*, *Agnostus cambrensis*, *Lingulella ferruginea*, and var. *ovalis*, *Obelella sagittalis*, *Theca penultima*, and *Discina pileolus*.

[1] Hicks, "On the Occurrence of Phosphates in the Cambrian Rocks," Quart. Jour. Geol. Soc., vol. xxxi. pp. 368–376, and Appendix by W. H. Hudleston, M A., F.G.S., &c., "On the Chemical Analysis of the Rocks," pp. 376–385.

CHAPTER VII.

LINGULA FLAGS.

Lingula Flags, or Ffestiniog and Dolgelly Groups.

Primordial Silurian, Murchison.
Grès blancs a *Scolithus, Lingula, Bilobites*, de Bretagne. (France.)
Primordial à Olenus de Hof. (Baviere.)
Regio A. *Olenorum*. Schistes alunifères supéreurs de Scanie, Oleland, Bornholm, &c. (Scandinavia.)
Potsdam sandstone, St. John's group. (America.)

Lingula Flag Group.—The fossiliferous strata lying above or succeeding the Menevian have been carefully investigated. These deposits are the Lingula flags of the Geological Survey and authors generally, and are equivalent to the Middle Cambrian of Sedgwick, and the Upper Cambrian of Lyell and Salter. The obscurity of these beds in the field, the smallness of the fauna, and the difference in physical condition in areas widely separated, render it difficult to draw lines of demarcation, or determine what should be embraced by the terms Lower, Middle, and Upper Lingula flags. The so-called Middle group has no stratigraphical or palæontographical value whatever, its fauna consisting of 5 species only. Three of these are Brachiopoda—*Kutorgina cingulata, Lingulella Davisii*, and *Lingula squamosa;* one Trilobite (*Conocoryphe? bucephala*), and *Bellerophon cambrensis*. These two last occur in the upper part of the Dolgelly beds of that area.

It must be remembered that the "Lower Lingula flags" of Sedgwick comprises the "Menevian group" of Salter and Hicks, and that the "Ffestiniog group" of Sedgwick constitutes the Middle and Upper Lingula flags of Salter. Care is therefore required when analysing or correlating these groups, either through their literature, or research in the field.

In physical characters the North Wales Lingula group differs altogether from those of South Wales. The arenaceous flags and shales with *Ling. Davisii* form only a subordinate part of a series of fine-grained dark blue and black slates containing many genera of Trilobites. The Ffestiniog beds are restricted to the flags containing *Lingulella Davisii* and *Hymenocaris vermicauda* (Plate I.) as originally defined by Sedgwick, and the slates and flags below them, or the Maentwrog group, characterised by peculiar *Oleni*. These beds are exhibited to great perfection at Maentwrog, S.W. of Ffestiniog.

The Maentwrog, Ffestiniog, and Dolgelly groups are palæontologically and lithologically distinct; none of the Trilobita pass from one group to another; peculiar genera occurring in each.

Maentwrog Group.—This group is readily distinguished by its jointed dark-blue ferruginous slates; the Ffestiniog by hard micaceous flags with numerous *Lingulella Davisii, Hymenocaris*, and *Conocoryphe;* and the uppermost or Dolgelly group by *Agnostus*

nodosus, *A. princeps*, and *Olenus gibbosus*, abounding in the soft black slate, which shows a black streak when scratched. They are conformable to the blue-black Menevian slates which mantle round the Merionethshire anticlinal. This lower group is about 700 feet thick. *Olenus gibbosus* and *Agnostus pisiformis* (*A. princeps*, Salt.) occur in the slates. The range between the rivers Eden and the Mawddach, and near Dolmelynllyn, in the Mawddach Valley, are the chief localities for fossils. They also occur on the northern flanks of Cader Idris and about Dolgelly, and most of the area west of Rhobell-Faur and the Arenigs, spreading to Ffestiniog, Maentwrog, and Traeth Bach, north of the Harlech Dome. In Caernarvonshire, between the Menai Straits and the Snowdon Mass, they are 4000 feet thick, and overlie the Great Penrhyn sandstones. They are most conspicuous from Tremadoc to Fron-y-gader and near Criceth. The Upper Maentwrog series is nearly 2000 feet thick. *Agnostus princeps* in the upper part, is associated with *Olenus truncatus*, occurring in thousands; the higher beds contain *O. cataractes*, which replaces *A. princeps*. This group is completely developed in the Maentwrog district, fine sections occurring in the Waterfall valley and in the valley running from Taffarn-helig to Caen-y-coed. *Olenus cataractes* abounds here.

At St. David's the lower beds are thin, ribbony-looking, and much contorted. *Olenus* is the characteristic fossil in these slaty flags, associated with *Hymenocaris*. The group here is divided into an upper and lower series.

Maentwrog Group.	Upper, 1800 feet	Slates and Flags, with *Olenus truncatus* and *Olenus cataractes*, &c.
	Lower, 700 feet	Sandy and Slaty Beds, with *Olenus gibbosus*, *Agnostus pisiformis*, &c.

Lower Ffestiniog Group.—Thick micaceous hard grey flags, 2000 feet thick, conformably overlie the Upper Maentwrog beds; the lowest series are bluish-grey slates, and contain *Lingulella Davisii*, with Annelid tracks; the highest part of the Lower Ffestiniog slates yields *Hymenocaris vermicauda*, only known in this middle division of the Lingula flags (Plate I. fig. 5).

Upper Ffestiniog Group.—This group succeeds the lower series, and is seldom more than 50 feet thick, but distinct in fossil contents. The characteristic forms here are *Olenus micrurus* (Plate I. fig. 7), *Conocoryphe bucephala*, and *Bellerophon cambrensis*. This thinly-developed division occurs at Gwern-y-barend, in the Mawddach, near Craig-y-dinas, and on Mynydd-Gader.

The river Mawddach cuts through the whole of these beds between Rhiwfelyn and Hafad-fraith, they then range across the east end of Moel Hafod-owen and by Pen-y-bryn, near Dolgelly.

Ffestiniog Group.	Upper, 50 feet	Bluish-grey Flags, with *Conocoryphe bucephala* and *Bellerophon cambrensis*, &c.
	Lower, 2000 feet	Arenaceous and Micaceous Yellowish-grey Flags, with *Lingulella Davisii*, *Hymenocaris vermicauda*, *Cruziana*, &c. (Plate I.)

Dolgelly Group — Upper Lingula Flags (Belt, 1867). — This uppermost division of the Lingula flags is physically divided into two series, lower and upper, the lower composed of hard blue and black slates abundantly filled with *Olenus* (*Parabolina*) *spinulosus*. The thickness of this series is about 300 feet.

The upper division differs essentially from the lower. It consists of soft black slates, with *black streak*, intensely cleaved and often pisolitic (fine grains of pisolitic iron ore). The constant character of the black streak distinctively marks this group, and in the most disturbed areas may be relied on as a never-failing criterion of the upper series. The black Olenus shales of Malvern, overlying the Hollybush sandstones, and containing *Olenus bisulcatus*, *O. scarabæoides*, *O. pauper*, *O. humilis*, *Conocoryphe malvernensis*, *Agnostus princeps*, *A. M'Coyi*, &c., belong here; they underlie the *Dictyonema* shales, and are exposed in the valley of the White-leaved Oak. The Upper Dolgelly beds are by far the most fossiliferous; and nearly every species is confined to this division.

Dolgelly Trilobites.—The Trilobites in the Dolgelly area are *Conocoryphe abdita*, *C. Williamsonii*, *C. longispina*, *Olenus scarabæoides*, *Sphærophthalmus* (*Olenus*) *alatus*, *S.* (*Olenus*) *humilis*, *Agnostus princeps*, *A. trisectus*, and *A. obtusus*, and, as before stated, the Malvern species are equally restricted. None of these occur below in the Middle and Lower Lingula flags. All through the Maentwrog, Ffestiniog, and Dolgelly deposits, the Trilobita that successively appear are closely allied, or belong to the Agnostidæ and Olenidæ; no new types of structure come in, the fauna being distinctive, similar and homogeneous as a whole. *Dikelocephalus*, *Conocoryphe*, *Olenus*, and *Paradoxides* constitute the natural group or family Olenidæ, and the single genus *Agnostus* is rich in species.

Change in the Trilobitic Fauna.—The succeeding Tremadoc and Arenig rocks evidence great and sudden change, faunal and otherwise, the large Asaphidæ, Cheiruridæ, Trinucleidæ, and Calymenidæ for the first time appearing; sixteen new genera at once occur in the Arenig, and two in the Tremadoc (*Niobe* and *Psilocephalus*); and we have no proof of any unconformity in either the North or the South Wales areas: these large forms come in at once and in vast numbers. Nor have we as yet any evidence of these new and distinct types having had prior existence in some other area, whence they migrated into the Tremadoc or Arenig seas; we know not at present where to look for evidence of this.

Foreign Representatives.—Ireland possesses no rocks or fossils of this age or earlier, Scandinavia none, Western Europe none. America then possessed gigantic species of *Asaphus*, but in which direction dispersion or distribution may have taken place we have no trace, although evidence tends to show that it must have been towards the east, or Europe, the main strike of the oldest American rocks being N.E. and S.W.; while the older groups are greatly developed on the eastern side of the North American continent, and there is considerable affinity between the faunas of the two areas, the

facies strongly resembling each other. No migration of an earlier fauna from one area would fully account for the disappearance of the earlier gigantic Trilobites, such as *Paradoxides*, *Plutonia*, and other equally important genera, *Erinnys*, *Holocephalina*, &c., all of which characterise the lowest rocks of Britain, ranging from the Harlech beds to the top of the Menevian.

The second division or *upper* part of the Lower Lingula flags (the typical Lingula flags) is finely developed in North Wales, near Tremadoc and Ffestiniog, at Maentwrog, Borth, Marchllyn-Mawr, Llanberis, Carnedd Ffiliast, Dolgelly, and Trawsfynydd.[1] *Cruziana semiplicata*, *Hymenocaris vermicauda*, *Olenus micrurus*, *Lingulella Davisii*, are the chief fossils. Physically these rocks are hard, grey, thick, sandy beds and flags.

The Upper Lingula flags consist of dense black pyritous slates, or black slates with pyritous bands near the base, and yielding a large fauna which differs almost entirely from that of the Lower Lingula flags. Out of 35 species occurring in the lower group, only 4 pass to the upper—namely, *Agnostus princeps*, *Lingulella Davisii*, *L. lepis*, and *Obolella sagittalis*, and this in the same district. At Tremadoc, Maentwrog, and west of Ffestiniog, the beds are rich in fossils—*Olenus alatus*, *O scarabæoides*, *Agnostus princeps*, *Conocoryphe depressa*, *C. invita*, *Orthis lenticularis*, and *Dictyonema* thickly crowding the beds.[2]

Palæontology of the Lingula Flags.—The analyses of the Lower and Upper Lingula flags must be taken separately. The faunas of the two horizons differ remarkably; and only 3 species connect them —namely, *Agnostus princeps*, *A. trisectus*, and *Anopolenus Salteri*. The Middle Lingula flags of some authors contain only 5 species—*Conocoryphe bucephala*, *Kutorgina cingulata*, *Lingula squamosa*, and *Lingulella Davisii*; with *Bellerophon cambrensis*. *Lingula squamosa* and *Bellerophon cambrensis* appear to be confined to this horizon.

Fauna of the Lower Lingula Flags—Protozoa.—*Protospongia fenestrata* passes up from the Menevian and Harlech beds at St. David's to the Lower Lingula flags.

Echinodermata.—None occur in the Lingula flags. The cystidean *Protocystites menevensis* is Menevian only; and the first known Crinoid (*Dendrocrinus*) appears in the Lower Tremadoc of Ramsey Island.

Annelida.—Three genera and 3 species. The characteristic *Cruziana semiplicata* (Salt.) has only been found hitherto in the Cambrian grits of the Bangor area, near Cwm Grainog and Carnedd Ffiliast, in North Wales (Lower Lingula flags of the Survey).

[1] Consult the fine geological maps of the Geol. Survey, those embracing the Snowdonian, Cader Idris, and Harlech areas.

[2] In 1851 Barrande visited England to compare his fine series of Bohemian fossils with our types, when he at once recognised the "Lingula flags" of Sedgwick as the precise equivalent of his primordial stratum (Étage C). Barrande carried out his comparison and correlation not only with the fauna of our country, but also between those of Europe and America, with what success, the literature and progress of geological science have shown. Consult his great work, "*Système Silurien du Centre de la Bohême*," 4to, Prague.

PLATE II.

LOWER SILURIAN FOSSILS.

1. *Macluria Peachii* (Salt.) Upper side—Lower Silurian. Durness. North-West Highlands—Llandeilo.
2. Operculum of *Macluria Peachii*.
3. *Macluria Logani* and operculum. Lower Silurian. Ayrshire (Llandeilo beds).
4. *Raphistoma æqualis* (Salt.) Caradoc or Bala beds; common in the Lower Silurian rocks of America.
5. *Oncoceras* sp. (*Phragmoceras*). Llandeilo beds, Durness. North-West Highlands.
6. *Orthoceras mendax* (Salt.) Durness. North-West Highlands.
7. *Ophileta compacta* (Salt.) Llandeilo beds, Durness.
8. *Murchisonia sub-rotundata*. Caradoc or Bala beds.
9. *Cyclonema rupestris* (Eichw.) Caradoc or Bala beds.
10. *Halysites catenulatus* (Lim.) Chain Coral, common in the Lower and Upper Silurian (Llandeilo to Wenlock).
11. *Echinosphærites balticus* (Eichw.) Caradoc or Bala. South Wales and Scandinavia, abundant.
12. *Echinosphærites granatus* (Wahl.) Llandeilo and Bala rocks. South Wales and Scandinavia.
13. *Sphæronites punctatus* (Forbes). Bala rocks.
14. *Agelacrinites Buchianus* (Forbes). Caradoc. South Wales.
15. *Sphæronites* (*Caryocystites*) *munitus* (Forbes). Bala beds.
16. Ovarian pyramid of *Echinosphærites*.
17. *Palæaster asperrimus* (Salt.) Caradoc or Bala.
18. *Palæaster obtusus* (Forbes). Bala beds. Wales and Ireland.
19. *Murchisonia obscura* (Portl.) Caradoc. Ireland.
20. *Helminthochiton Griffithii* (Salt.)
21. *Patella? Saturni* (*Discina?*). Llandeilo.

PLATE II.

LOWER SILURIAN FOSSILS.

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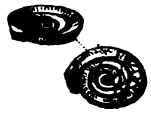

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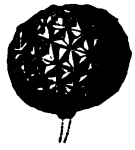

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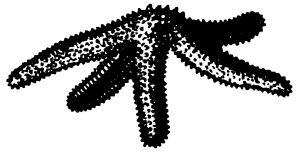

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21

Specimens of this *Cruziana* or an allied species have occurred below the Stiper-stones in the Shelve country, west of the Longmynds.

Crustacea.—Nine genera and 25 species have been described, 14 having appeared before in the Menevian, and therefore occur in both formations; 2 species (*Agnostus princeps* and *A. trisectus*) pass to the Upper Lingula flags. It is the home of *Agnostus*, 6 species occurring; but only 2 are peculiar or confined to the Lower Lingula flags, viz., *Agnostus limbatus* and *A. nodosus;* besides these *Olenus cataractes*, *O. micrurus*, *O. gibbosus*, and *O. truncatus?* are also confined to this horizon. *Hymenocaris vermicauda* essentially characterises the Lower Lingula flags. So that, large as the Crustacean fauna appears (25 species), there are only 8 species that are really Lower Lingula forms. The genus *Conocoryphe*, which is very largely represented in the Lower Cambrian rocks (by no less than 21 species), has no distinctive or peculiar species in the Lower Lingula flags. Nine species of this genus occur in the Upper Lingula flags, and that division possesses more peculiar forms and a larger specific Crustacean fauna than the Lower Lingula flags, but fewer genera. The species are as follows:—*Agnostus obtusus*, *A. princeps*, *A. trisectus*, *A. Turneri*, *A. venulosus*, *Ampyx prænuntius*, *Conocoryphe abdita*, *C. depressa*, *C. invita*, *C. malvernensis*, *C. longispina*, *C. Plantii*, *C. simplex*, *C. Williamsoni*, *Olenus bisulcatis*, *O. flagellifer*, *O.* (*Sphæropthalmus*) *humilis*, *O. obesus*, *O. pauper*, *O. pecten*, *O.* (*Peltura*) *scarabæoides*, *O. serratus*, and *O. spinulosus*.

TABLE V.—Lower Lingula Flags.

From Menevian.	Classes.	Genera.	Species.	Pass to Middle Lingula Flags.	Pass to Upper Lingula Flags.
	Plantæ.				
¼	Protozoa	1	1		
	Hydrozoa.				
	Actinozoa.				
	Echinodermata.				
	Annelida	3	3		
8/14	Crustacea	9	25	¼	2/3
	Polyzoa.				
⅓	Brachiopoda . . .	3	5	¼	⅓
	Pelecypoda.				
	Gasteropoda.				
¼	Pteropoda	1	2		
	Heteropoda.				
	Cepthalopoda.				
11/17	.....	17	36	⅓	¼

Brachiopoda.—*Lingulella* and *Obolella* are the only genera in the Lower Lingula flags. The species are *Lingulella Davisii* and *L. lepis* (both ranging to the Arenig rocks), *L. ferruginea*, *Obolella maculata*, and *O. sagittalis*. The last-named species is also of Tremadoc age.

Pteropoda.—*Theca corrugata* and *T. obtusa* are the only 2 species known. The last-named is confined to the Lower Lingula flags.

Heteropoda.—None below the Middle Lingula flags; and the only species occurring therein is *Bellerophon cambrensis*, the first-known species.

Besides the absence of plants, the following classes of invertebrata are unrepresented in the Lower Lingula flags:—the *Hydrozoa*, *Actinozoa*, *Echinodermata*, *Polyzoa*, *Pelecypoda*, *Gasteropoda*, *Heteropoda*, and *Cephalopoda*.

Upper Lingula Flags.

Fauna of the Upper Lingula Flags—Annelida.—Two genera, *Scolicoderma antiquissimum* and *Serpulites fistula*. The Hollybush sandstone of the Malverns is characterised by the two Annelides above named; the Hollybush beds of the Wrekin also contain Annelide remains. *S. fistula* first appears in the Menevian beds. Whatever may be the age of the Hollybush sandstones, these two species occur in the Malvern area, at the base of the Upper Lingula flags.

Crustacea.—Twenty-six species represent the following 5 genera —*Agnostus* 5 species, *Ampyx* 1, *Conocoryphe* 9, *Dikelocephalus* 2, *Olenus* 9. Four species, viz., *Agnostus princeps*, *Ampyx prænuntius*, *Conocoryphe depressa*, and *Olenus alatus*, pass from the Upper Lingula flags to the Lower Tremadoc, and 20 species are confined to this horizon. Thus the Upper Lingula flags through the Crustacean fauna become of much importance, and the few species (4) that pass to the Tremadoc, clearly prove the stratigraphical value of the Lingula flag group. Only 2 species pass from the Upper Lingula flags to the Upper Tremadoc, namely *Agnostus princeps* and *Ampyx prænuntius*.

Polyzoa.—*Dictyonema sociale* (Salt.) is the only Polyzoon known; it also occurs in the Lower Tremadoc rocks, both in the North and South Wales areas, at Tremadoc and St. David's, and is characteristic of the pale *Dictyonema* shales that overlie the black shales in the valley of the White-Leaved Oak, at the southern end of the Malvern range.[1] These black and pale-greenish Upper Lingula shales are about 500 feet thick, and contain a singular Crustacean fauna. Professor Phillips first noticed these shales and their fossil contents.[2] The Crustacea are *Conocoryphe malvernensis*, *Olenus bisulcatus*, *O. humilis*, *O. spinulosus*, *O. pauper*, *Sphærophthalmus pecten*, *Agnostus M'Coyi?* and *A. princeps*; the Brachiopoda are *Lingula pygmæa*, *Obolella Salteri*, and *Spondylobolus*, sp.; many of these are peculiar to the Malvern area. Dr. Holl[3] in 1865 described the geological structure of the Malvern Hills and adjacent districts, plac-

[1] It is possible that Kjerulf's *Fenestella socialis* from Scandinavia may be our *Dictyonema*; Eichwald's *Gorgonia flabelliformis*, although much larger, is almost identical; Mr. Salter, however, established its generic distinctness.

[2] Mem. Geol. Surv. of Great Britain, vol. ii. part 1, "On the Malvern Hills."

[3] Quart. Jour. Geol. Soc. vol. xxi. 1865, pp. 72–102.

ing these shales in the Upper Cambrian, the Hollybush sandstone being the base or lowest known sedimentary rock in the Malvern area.

Brachiopoda.—Only 5 genera and 8 species occur in the Upper Lingula beds—*Kutorgina cingulata, Lingulella Davisii, L. lepis, Lingula pygmæa, Obolella plicata, O. Salteri, O. sagittalis,* and *Orthis lenticularis. Kutorgina cingulata, Lingulella Davisii, L. lepis, Obolella plicata, O. sagittalis,* and *Orthis lenticularis,* pass to the Tremadoc rocks. Two species only, *Lingula pygmæa* and *Obolella Salteri,* are really restricted to the Upper Lingula flags.

Pteropoda.—Of the 4 genera and 17 species that range from the Longmynd group of St. David's to the Upper Tremadoc, no form has yet been obtained from the Middle or Upper Lingula flags.

Summary.—Between the close of the deposition of the Menevian rocks and the close of the Upper Lingula flags, 10 new genera appeared, viz., *Cruziana, Scolicoderma, Helminthites, Dictyonema, Parabolina, Dikelocephalus, Peltura, Hymenocaris, Lingulella,* and *Kutorgina.* Only 1 of these (*Lingulella*) lived on after the deposition of those sediments we term Lingula flags; the genus Lingula has since appeared in almost every successive marine formation known.

Nine invertebrate classes are unrepresented in the Upper Lingula flags; only the Crustacea and Brachiopoda have real value.

In the Lower Lingula flags the 25 species of Crustacea stand alone; and, with the exception of *Hymenocaris vermicauda, Leperditia Hicksii,* and *Primitia solvensis,* are all Trilobita. Only 2 species pass to the Upper Tremadoc, *Agnostus princeps* and *Ampyx prænuntius;* none survive to the Arenig.

TABLE VI.—Upper Lingula Flags.

From Lower Lingula Flags.	Classes.	Genera.	Species.	Pass to Lower Tremadoc.	Pass to Upper Tremadoc.
	Plantæ.	None.	None.		
	Protozoa.	...	...		
	Hydrozoa.	...	...		
	Actinozoa.	...	...		
	Echinodermata.	...	...		
	Annelida	2	2		
$\frac{3}{3}$	Crustacea	8	30	$\frac{4}{4}$	$\frac{2}{2}$
	Polyzoa	1	1	$\frac{1}{1}$	
$\frac{3}{3}$	Brachiopoda . . .	5	8	$\frac{4}{5}$	$\frac{3}{5}$
	Pelecypoda.	None.	None.		
	Gasteropoda.	...	...		
	Pteropoda.	...	...		
	Heteropoda.	...	...		
	Cephalopoda.	...	...		
$\frac{4}{4}$	.....	16	41	$\frac{9}{10}$	$\frac{4}{7}$

Tremadoc Rocks.

Tremadoc group, Sedgwick, 1847.
Tremadoc slates, Sedgwick, 1847.
Upper Cambrian, Salter and Hicks.
Lower Llandeilo, or Arenig beds. (Quebeck Group.)
Minerai de Fer de Falaise. (Calvados, France.)
Etage D. I., *Schistes à nodules.* (Barrande, Bohemia.)
Regio B. C., *Ceratopygarum.* (Angelin, Scandinavia.)
Calciferous sandrock, *Champlain Division.* (North America.)

Prior to the year 1865 little or nothing was known of the Tremadoc rocks in the promontory of St. David's, but in North Wales they had been studied by Professor Sedgwick and Mr. Salter. The determination by Mr. Callaway of the presence of this Tremadoc fauna in Shropshire is of high importance,[1] as most of the Shineton Tremadoc species and many of the genera are new. The Shineton species having most value are *Conocoryphe monile, Olenus Salteri, Olenus triarthrus, Agnostus dux, Lingulella Nicholsoni, Obolella sabrinæ, Asaphus* (*Asaphellus*) *Homfrayi, Asaphus* (*Platypeltis*) *Croftii.*

Shineton Shales.—The Shineton Shales may be passage-beds between the Lingula flags and the Lower Tremadoc, a view which the presence of *Dictyonema sociale* strengthens; it is an Upper Lingula flag species at Malvern, Pedwardine, and many places in North Wales, as well as a well-known Tremadoc form in the latter area. Mr. Callaway describes 14 new species in the Shineton area; establishes 2 new sub-genera of Trilobites, *Asaphellus* and *Platypeltis*, and 2 genera, *Conophrys* and *Lichapyge;* and further determines a new and remarkable Cystidean, *Macrocystella Mariæ.*

No true Tremadoc rocks are known in the Stiperstones area; nor, indeed, are we sure of the presence of the true Lingula flags in that district west of the Longmynds, unless the Stiperstones represent these; but of this we have neither stratigraphical nor organic proof, the series succeeding being of Arenig or Skiddaw age.

The Tremadoc slates of the two classic localities, viz., Tremadoc in North Wales, and St. David's in South Wales, are so rich in conspicuous and well-determined species, that we readily place them in two separate horizons or zones. Their true position in North Wales, between the Lingula flags below and the Arenig group above, was clearly fixed by Professor Sedgwick in 1851. Small, however, was the known fauna to the distinguished professor, when in 1843 at Tai-hirion, west of Arenig Mountain, only two characteristic fossils, *Ogygia Selwynii* and *Calymene parvifrons*, were collected. These 2 species, the only ones then known, defined the basis of Sedgwick's Arenig group, and determined the top of his Tremadoc series. The Tremadoc fauna of North Wales consists of 42 species, South Wales 30, and Shropshire (Shineton) 16. The Arenig group numbers 62 genera and 149 species, 97 occurring in the St. David's area, 74 in

[1] Callaway "On the Cambrian Rocks of South Shropshire," Quart. Jour. Geol. Soc., vol. xxxiii. pp. 652-672.

the Skiddaw beds of Westmoreland, 36 in the Stiperstones area, and 34 in North Wales. These have all been added and described since the far-seeing eye of Sedgwick determined the stratigraphical place of the group on physical grounds.

Tremadoc Rocks of South Wales.—The discovery of the occurrence at St. David's of Tremadoc slates equivalent to those of North Wales throws new light upon the history of that remarkable promontory. The Ramsey Island section is stratigraphically complete, having for its conformable base the Lingula flags, full of *Lingulella Davisii;* while upon the Tremadoc rocks (here 1000 feet thick) succeed the Arenigs, thus affording, as at Whitesand Bay, clear proof of the intercalated position of the Tremadoc group. In North Wales no Arenig rocks are yet known to *rest anywhere directly upon the Tremadoc rocks.* Twenty-nine species are found in the Ramsey Island section, 24 of which are new; and 15 occur inland at Tremanhire, east of St. David's.

The occurrence in Ramsey Island of the earliest known Pelecypoda or Lamellibranchiata in Britain, if not in Europe, is remarkable. The Lower Tremadoc beds in that island have yielded 5 genera and 12 species, the first representatives known of that order; 6 of the same species occur inland at Tremanhire. Three of these genera belong to the Arcadæ, and one probably to the Anatinidæ; prior to this discovery, *Redonia*, *Ribieria*, and a species of *Palæarca* were the oldest forms known, and were obtained from the Arenig beds at Lord's Hill, Shelve. The last-named genus has been obtained from Cambrian rocks in Spain, Bohemia, France, and Devonshire. These bivalves are also associated with the earliest known Crinoid and Starfish, *Dendrocrinus cambrensis*, and *Palæasterina ramseyensis.* Still more significant zoologically is the presence of a new genus of Trilobite (*Nesuretus*) with 4 species. These 4 species are all confined to the Lower Tremadoc rocks of Ramsey Island and Tremanhire on the St. David's promontory. None had occurred in North Wales until discovered by Professor Hughes in Anglesey. If any other Trilobite were required to establish palæontological relationship between the Tremadoc rocks of North and South Wales, it would be Angelin's genus *Niobe*, which is not known out of the Tremadoc group.

The South Wales beds do not possess so numerous an assemblage of pelagic Mollusca as those of North Wales: *Theca Davisii*, *T. opercula*, are Lower Tremadoc only; *T. arata*, *T. bijugosa*, *T. cuspidata*, Lower and Upper; *T. alata*, *T. simplex*, and *T. trilineata*, with *Conularia Homfrayi*, are Upper Tremadoc; and 5 Heteropoda (*Bellerophon arfonensis*, *B. multistriatus*, *B. ramseyensis*, *B. solvensis*, and *B. shinetonensis*) range through the Tremadocs; but *Theca Davisii*, *Bellerophon ramseyensis*, and *B. solvensis* are South Wales species. Associated with *Niobe menapiensis* and the *Nesureti* no less than 19 species occur, including the 12 Pelecypoda and 5 Brachiopoda, viz., *Lingulella Davisii*, *Lingula petalon*, *Obolella plicata*, *Orthis Carausii*, and *O. menapiæ.* The Middle Tremadoc contains *Cheirurus Frederici*, *Conocoryphe verisimilis*, *C. vexata*, and *Asaphus*

Homfrayi,—the upper division consisting of iron-stained slates and flags. The Portmadoc area is characterised by *Angelina Sedgwickii*, *Lingulocaris lingulæcomes*, and *Conularia Homfrayi*. The distinctness of the Tremadoc from the Lingula flags below is the same in all areas; only 8 out of 65 known forms in the former pass up to the Tremadoc, which possesses a fauna of 84 species; these are *Agnostus princeps*, *Ampyx prænuntius*, *Conocoryphe depressa*, *Lingulella Davisii*, *L. lepis*, *Orthis lenticularis*, *Obolella sagittalis*, and *Dictyonema sociale*. Forty-two species are known in North Wales, and 30 in South Wales; yet only 3 species are common to both areas—*Niobe Homfrayi*, *Lingulella Davisii*, and *L. lepis*.

Characteristic Fossils.—The most characteristic fossils of the Lower Tremadoc are *Niobe Homfrayi*, *N. sapiensis*, *Psilocephalus innotatus*, *Angelina Sedgwickii*, and *Asaphus affinis*; these five species are met with wherever these rocks are well seen.

The true Upper Tremadoc series is characterised by many new and distinct species. *Niobe Homfrayi*, *Psilocephalus innotatus*, and *P. inflatus* are replaced by *Asaphus Homfrayi* and *Angelina Sedgwickii*; *Cheirurus Frederici* at Garth, Llanerch, Penclogwyn, Portmadoc, &c. These range from the top of the Lower Tremadoc rocks through the passage-beds, and all through the Upper Tremadoc series into the Arenig.

It is clear that there is no stratigraphical or palæontological break between the Lingula flags and the Tremadoc beds: both areas prove conformability by direct evidence; and 9 species connect them palæontologically, viz., *Dictyonema sociale*, *Agnostus princeps*, *Ampyx prænuntius*, *Conocoryphe depressa ?*, *Olenus impar*, *Lingulella Davisii*, *L. lepis*, *Obolella sagittalis ?*, and *Orthis lenticularis*. Three of these same species also connect the Tremadoc and Arenig rocks: they are *Lingulella Davisii*, *L. lepis*, and *Orthis lenticularis*. All palæontological evidence goes to prove "that the Tremadoc rocks of the St. David's area are closely allied to, if not identical with, the lower portion of the Tremadoc rocks of North Wales." The whole Tremadoc fauna consists of 33 genera and 86 species. The Arenig fauna includes 62 genera and 149 species, with 42 species of Hydrozoa. The succeeding Llandeilo has yielded 230 species.

Palæontology of the Lower Tremadoc Rocks.

Hydrozoa.—The Shineton Tremadoc rocks have yielded 2 species, *Clonograptus* and *Bryograptus Callavei* of Lapworth, both belonging to the family Dichograptidæ. These are the *oldest Rhabdophora known*.

Actinozoa.—None known below the Llandeilo rocks.

Echinodermata.—*Dendrocrinus cambrensis*, Hicks, and *Palæasterina ramseyensis*, Hicks, are both from the Lower Tremadoc beds of Ramsey Island, St. David's; they *are the first known species* of the orders Crinoidea and Asteroidea.

Crustacea.—Only 2 new genera appear with the coming-in of the

Lower Tremadoc (*Psilocephalus* and *Neseuretus*); but the whole Crustacean fauna comprises 13 genera and 24 species, of which 10 genera and 19 species *especially characterise* the Lower Tremadoc. They are so essential to a right understanding of the Lower Tremadoc rocks, and so distinct from the fossils of the Upper Lingula flags, that we enumerate them :—*Agnostus Barlowii*, *A. dux*, *Conophrys salopiensis*, *Asaphus Croftii*, *Dionide atra*, *Lichapyge cuspidata*, *Nesuretus* (5 species), *Niobe Homfrayi*, *N. menapiensis*, *N. solvensis*, *Conocoryphe verisimilis*, *Olenus triarthrus*, *O. Salteri*, *Psilocephalus inflatus*, and *P. innotatus*. None of the above species occur below or above the Lower Tremadoc horizon. The remaining five occur also in the Upper Lingula flags, and unite the two formations. The chief species occur at Penmorfa, Borthwood, and Llanerch in Caernarvonshire, and Dudreath and Tyn-y-llan in Merioneth; and the same are met with in the St. David's promontory at Whitesand Bay, &c. Nowhere do the above-mentioned forms transgress the lower beds. The Lower and Upper Tremadoc are connected only by *Agnostus princeps*, *Ampyx prænuntius*, and *Ogygia scutatrix*.

Polyzoa.—*Dictyonema sociale* as in the Upper Lingula flags, also near Tremadoc in the passage beds.

Brachiopoda.—The Lower Tremadoc Brachiopoda are *Kutorgina cingulata*, *Lingula petalon*, *Lingulella Nicholsoni*, *L. lepis*, *Obelella Beltii*, *O. sabrinæ*, *O. plicata*, and *O. sagittalis*. *Orthis carausii*, *O. lenticularis*, and *O. menapiæ*. Four of these 5 genera and 6 of the 11 species pass to the Upper Tremadoc. They are *Lingula petalon*, *Lingulella lepis*, *Obolella Beltii*, *O. plicata*, *Orthis carausii*, and *O. lenticularis*.

Pelecypoda (Lamellibranchiata).—The Tremadoc rocks of Ramsey Island have yielded the first evidence of Pelecypod or bivalve molluscan life in Britain. They are referable to 5 genera and 12 species —*Davidia* (2), *Glyptarca* (2), *Modiolopsis* (4), *Palæarca* (2), and *Ctenodonta* (2); none of the species are known out of, or above the Lower Tremadoc.

Gasteropoda.—None known below the Arenig rocks.

Pteropoda.—The genus *Theca* is represented by 5 species in the Lower Tremadoc, viz., *Theca ovata* (Salt.), *T. bijugosa* (Salt.), *T. cuspidata*, *T. Davisii*, and *T.* (*Cleidotheca*) *operculata*. The 3 first named pass to the Upper Tremadoc. *T. Davisii* is the only species at St. David's. The remaining 4 are North-Welsh forms.

Heteropoda.—*Bellerophon ramseyensis* and *B. solvensis* characterise the Tremanhire or Solva and Ramsey Island beds.

Cephalopoda.—None below the Upper Tremadoc.

Palæontology of the Upper Tremadoc Rocks.

Annelida.—Tracks only.

Crustacea.—11 genera and 15 species comprise the Crustacean fauna of the Upper Tremadoc; 12 of the 15 are Trilobita; 6 of these 15, viz., *Asaphus affinis*, *A. Homfrayi*, *Cheirurus Frederici*, *Dionide atra*, *Ogygia scutatrix*, and *O. Selwynii*, pass to the Arenig.

The following Crustacea are the only species confined to the Upper Tremadoc—*Angelina Sedgwickii, Conocoryphe olenoides, Olenus impar, Ceratiocaris latus,* and *Lingulocaris lingulocomes.* We are careful to name these, as the first palæontological break between the Cambrian and Silurian takes place here, and that without any stratigraphical or physical unconformity. No greater faunal change is known through the whole of the Lower Palæozoic rocks than at the close of the Tremadoc.

Brachiopoda.—Only 4 genera and 7 species occur, and 6 of these pass to the Arenig. They have therefore no stratigraphical value. *Obolella Belti* is the single restricted form.

Pteropoda.—*Conularia* and *Theca*—the first, *C. Homfrayi*, is also Arenig; the latter contains 6 species, one of which (*Theca simplex*) passes to the Arenig.

Heteropoda.—*Bellerophon arfonensis* and *B. multistriatus* are the only Upper Tremadoc species. The last named is Arenig also.

Cephalopoda.—*Cyrtoceras præcox* and *Orthoceras sericeum;* the last also passes to the Arenig; *they are the first Cephalopods known in Britain.*

Summary of Lower Cambrian Life.—The accompanying Table shows the numerical value and stratigraphical distribution of the species *through all the Lower Cambrian divisions,* from the Longmynd and Harlech group to the close of the Tremadoc, and also shows in

TABLE VII.

Classes.	Genera.	Species.	Longmynd, &c.	Menevian.	Lower Lingula flags.	Upper Lingula flags.	Lower Tremadoc.	Upper Tremadoc.	Pass to Arenig.
Plantæ?	?	?	...	...	...	...	...	...	...
Protozoa	1	4	1/4	1/4	1/4	...	...	...	...
Hydrozoa	2	2	1/2	...	...	...	1/2	...	...
Echinodermata	4	4	...	1/4	...	...	1/4	...	...
Annelida	7	9	4/9	3/9	3/9	3/9	...	...	...
Crustacea	34	110	15/110	13/110	15/110	15/110	13/24	11/15	6/6
Bryozoa	1	1	...	...	...	1/1	1/1	...	...
Brachiopoda	7	18	3/3	3/3	3/3	3/3	5/11	4/7	6/6
Pelecypoda	5	12	...	...	...	...	1/12	...	...
Gasteropoda	...	...	...	...	...	...	...	...	...
Pteropoda	4	16	1/3	2/6	1/3	...	1/6	2/3	2/2
Heteropoda	1	5	...	...	1/5	...	1/5	1/5	1/1
Cephalopoda	2	2	...	...	...	...	...	1/2	1/1
	68	185	19/31	23/52	17/37	15/37	21/60	20/38	12/16

the last column the number of species that pass to the Arenig. It will be seen that 12 genera and 16 species survive to the Arenig. This special Table shows the commencement of life in the lowest

rocks of the British Islands; there is, therefore, no fauna older than those expressed by the number 61 genera and 182 species. Their ancestors we know not; neither do we know whence was derived the fauna given under the 11 classes. This Table shows the known fauna of the whole range of strata, from the Longmynd rocks to the top of the Tremadoc.

In this record of the earliest fossils known, the numerous blanks show that the classes were not represented or had not appeared in the British Isles.

CHAPTER VIII.

ARENIG OR SKIDDAW SERIES.

(Lower Llandeilo of Murchison; Middle Cambrian, Sedgwick.[1])

Geographical Distribution.—As far back as 1843, Professor Sedgwick determined the presence of certain slates in North Wales, west of Arenig Mountain, which contained peculiar fossils such as the Trilobites (*Calymene parvifrons* and *Ogygia Selwynii*), with some Graptolites. These rocks were at that time termed "*Tremadoc slate*," the fossils of the Arenig group not being then known in Shropshire or determined in North Wales.

This new series Sedgwick named the "*Arenig slates and porphyries.*" They rest conformably upon the underlying "*Tremadoc slates.*" He also termed them "*A great group of roofing slates, and contemporaneous porphyry.*" They are developed in the mountain-chains of *Arenig, Arran Mowddy*, the *Ffestiniog mountains*, and *Cader Idris*, and are conspicuously seen at St. David's in the cliffs at Whitesand Bay, the coast between Porth Melgan and Abereiddy Bay, and the middle part of Ramsey Island. The Arenig rocks of St. David's are chiefly black slates, conformably succeeding and resting upon the Tremadoc group along the course above named. They appear to have been deep-sea accumulations, and the whole series is about 4000 feet thick. The groups differ, both lithologically and palæontologically, in their northern and southern development. The North-Welsh group consists of iron-stained, black, and fine-grained dark grey slates, and ashy beds, well developed at Ty-obry and Tan-yr-Allt near Portmadoc; also at Borthwen-mawr at Tai-hirion, and places east of Ffestiniog; part of the Ffestiniog mountains above the "*grit bed*," embracing the great slate band (in which are worked the extensive slate quarries of Ffestiniog) and other beds termed "Lower Llandeilo" in that region.

The Arenig or Skiddaw group of Sedgwick immediately underlies the Llandeilo flags, and forms the base of the Silurian series. Sedg-

[1] The base of Arenig and Arran Fowddy. The Stiperstone Rocks.

wick recognised these beds as being different from the Llandeilo above, and called them Arenig slates, believing them *at the time* to be the top of his Ffestiniog rocks. The group is distinctly recognised in the lead-mining district of the Stiperstones area, east of the Longmynd, underlying the true Llandeilo flags of Shelve and Corndon Hill (the Lower Llandeilo of Murchison). The Arenig group near St. David's passes upwards into the Llandeilo flags, which are so finely shown in Abereiddy Bay. The distinctness of the Arenig series from the succeeding Llandeilo is clear, both physically and palæontologically.

There is a perfect, continuous, and conformable succession from the Tremadoc beds into the Arenig rocks, though it is seldom seen, even in the areas where they are typically developed. Neither in the Shelve and Stiperstones districts, where 36 species are known, nor in the Skiddaw area, which yields 76 species, has any downward stratigraphical succession been definitely determined.

In South Wales, however, at St. David's, their base rests conformably upon the Tremadoc, and their summit is overlain by the Llandeilo beds of Abereiddy Bay, both clearly defined. The three divisions here have yielded no less than 96 species, 40 of which are Hydrozoa, and 31 Crustacea (*Trilobita*). No Rhabdophora are known below the Arenig rocks. Six Crustacea out of the 31 are derived from the underlying Tremadoc, and only 3 pass to the Llandeilo; 22 species are therefore peculiar to the Arenig series. Of the whole Arenig fauna, comprising 150 species, 111 are confined to it. No more distinct group occurs in the British Islands.

Arenig Rocks of North Wales.

The Arenig slates and porphyries of North Wales form a distinct and well-marked sub-group resting upon the underlying Tremadoc slate. It is also the "great roofing-slate series with contemporaneous porphyry occurring in the chains of Arenig, Aran Mowddwy, Cader Idris, and in the Ffestiniog mountains, or the western base of the Arenigs and Arran, and probably the Stiperstone rocks."

Stratigraphical Position.—The true position of the Arenig group in North Wales long remained doubtful. The succession across the Penrhyn promontory, from the Lingula flags to the Arenig beds, is complete; it is here that the Tremadoc and Arenig series are typically developed in North Wales, the close of the Tremadoc and base of the Arenig being everywhere marked by the presence of a peculiar and well-defined band of "grit," varying in thickness. This line is the base of the Arenig rocks. Although occasionally obscured by faults, it is never lost, and should be traced by all who would understand the succession and division between the Tremadoc and Arenig series in North Wales. The fossils, when seen, at once determine the position—*Psilocephalus innotatus*, *Niobe Homfrayi*, *Asaphus Homfrayi*, *Lingulella Davisii*, and *Dictyonema sociale* illustrate *the lower part of the Tremadoc*, and *Angelina Sedgwickii*, *Asaphus Homfrayi*, and *Ogygia scutatrix* at Garth and Penclogwyn define *the upper part*

of the Tremadoc; whereas, succeeding the grit-band above named, at Ty-obry, Tai-hirion, &c., *Calymene Murchisoni*, *Asaphus affinis*, *Dionide atra*, and *Æglina caliginosa* are the characteristic Arenig forms. About 16 species connect the two groups. This physical line, when once determined, is a marked feature at the base of the Arenigs, separating the two formations. Beneath the grit at Garth Hill and Deudreath occur the upper beds of the Upper Tremadoc slates (hard grey flags), rich in fossils, including *Asaphus Homfrayi*, *Angelina Sedgwickii*, *Ogygia scutatrix*, *Lingulocaris lingulæcomes*, *Cheirurus Frederici*, and *Conularia corium*.

This zone, all along its course, indicates and ushers in a new set of conditions, both physical and palæontological. No Rhabdophora occur below this line anywhere; but in the black slates immediately overlying it at Garth, &c., they occur in plenty; associated with certain species of *Homalonotus*, *Asaphus*, *Calymene*, *Æglina*, and *Dionide*, accompanied by *Conularia* and *Pelecypoda;* and among the lower beds of the volcanic rocks of the Manods, *Calymene parvifrons* and *Trinucleus Murchisoni* occur, accompanied still farther eastward by *Ogygia Selwynii*, the species, of all others, which characterises the Arenig rocks of Shelve and Skiddaw, and which also occurs at Llanfaelrhys, in South Caernarvonshire, associated with *Lingula attenuata* and *Graptolithus Murchisonii*. Comparing the value of the Arenig series in North with that of South Wales, it is important to remember that, of the whole Arenig fauna in South Wales (97 species), only 5 are common to the two areas: these are *Calymene parvifrons*, *Ogygia Selwynii*, *Æglina caliginosa*, *Lingulella Davisii*, and *Orthis lenticularis*.

The dark slates at Ty-obry, which immediately overlie the "Grit," contain *Calymene parvifrons*, *Æglina caliginosa*, and *Dionide atra*, associated with *Diplograptus mucronatus*, *Climacograptus confertus*, and *Glossograptus ciliatus*, all Lower Arenig species. *Palæarca socialis* and a species of *Ctenodonta* are the only North Wales bivalves, and *Conularia corium* and *C. margaritifera* the only two Arenig pteropods known in North Wales. None of these occur at St. David's, and none pass to the Llandeilo group in any area.

Arenig Rocks of South Wales.

St. David's.—The Arenigs of St. David's consist mostly of black slates, resting conformably upon the Tremadoc group on the N. and N.E. side of the anticlinal, and they may be continuously traced for many miles. They also occur at Ramsey Island, and are 4000 feet thick, and must have occupied a vast period of time during their deposition, or sedimentation, as proved by their varied and distinct faunas.

The Arenig group may be divided into three sub-groups, the Lower, Middle, and Upper:—

The Lower, or black slaty Arenig, strikes E.N.E. and W.S.W.,

and has a vertical dip. The cliffs exposed on the N. coast of Whitesand Bay and the middle part of the N. end of Ramsey Island at Road-uchaf, yield the chief fossils. Numerous species of Graptolites (about 40), mostly new to Britain, with many new Dendroid species, have been obtained from this lower sub-group; the chief species are *Dendrograptus arbuscula*, *D. divergens*, *Dictyograptus cancellatus*, *D. radiatus*, and *Callograptus*. The Trilobites are *Asaphus Homfrayi* and *Ogygia scutatrix*, with *Conularia Homfrayi* and *Lingulella Davisii*; these especially characterise this lower division, and are associated with *Phyllograptus stella*, *Trigonograptus ensiformis*, *Callograptus radiatus*, and *Ptilograptus Hicksii*. Twenty-five species occur in the lower division, 28 in the middle, and 33 in the upper. *Asaphus Homfrayi*, *Ogygia scutatrix*, and *Conularia Homfrayi* are Upper Tremadoc as well as Lower Arenig forms, and connect the two formations. We are not aware that *Lingulella Davisii* ever again appears above this horizon in the Cambro-Silurian rocks.

The Middle or slaty and flaggy group is also best seen at Whitesand Bay, and is 1500 feet thick. This locality has furnished *Ogygia bullina*, *O. peltata*, *Æglina grandis*, *Trinucleus Gibbsii*, *T. Sedgwickii*, *Ampyx Salteri*, *Lingula petalon*, and *Orthoceras sericeum*, with 6 genera and 11 species of Rhabdophora; all the above are essentially characteristic of and confined to the middle subdivision. Of the Rhabdophora the chief are *Tetragraptus crucifer*, *T. serra*, *T. Hicksii*, *T. Halli*, *Clematograptus implicatus*, *Callograptus elegans*, and *C. Salteri*.[1]

The Upper Arenig.—Lithologically this division resembles the Lower, being composed of fine-grained dark shales, 1500 feet thick; they underlie the true Lower Llandeilo east of Abereiddy Bay, and are conspicuous through the new and distinctive fauna, and the first appearance of many genera of Trilobites, which mark a complete and progressive change from the Tremadoc fauna below to the succeeding Llandeilo series. Llanvirn quarry, E. of Abereiddy Bay and Porth-haog, W. side of Ramsey Island, has yielded a rich group of species "distinct from any previously discovered in any part of the Arenig series at St. David's."[2] Most of the genera are new, and several which appear for the first time culminate in the succeeding Llandeilo and Caradoc rocks; these are *Illænus*, *Illænopsis*, and *Barrandia*, each having a representative species, with *Placoparia*, a genus new to Britain, hitherto only known in France, Bohemia, and Spain. The genus *Placoparia*, with *Illænus*, *Illænopsis*, *Barrandia*, and *Phacops*, appear for the first time in the British Silurian rocks, associated with the earlier genera *Æglina*, *Calymene*, and *Trinucleus*. *Æglina obtusicaudata*, *Placoparia cambrensis*, *Barrandia Homfrayi*, and *Illænus Hughesii*, together with *Trinucleus Ramsayi*, and *T. Etheridgii*, must be regarded as the characteristic

[1] *Vide* Hopkinson, Hicks, and Lapworth. Quar. Jour. Geol. Soc., vol. xxxi. pp. 631–672.

[2] Dr. Hicks, Quar. Jour. Geol. Soc., vol. xxxi. p. 174.

Crustacea of the Upper Arenig group, the singular genus *Trinucleus* also appearing in the Middle Arenig for the first time. Numerous genera and peculiar species of Rhabdophora occur at Llanvirn and Ramsey Island. The fauna is essentially Silurian, for with the exception of a few Brachiopoda and *three* genera of Trilobita, no other Cambrian genera pass up from the Tremadoc rocks. These three are *Asaphus, Agnostus*, and *Ogygia*, species of which occur in the Upper Tremadoc. The occurrence here of Placoparia is important as bearing both upon distribution and correlation. The Gasteropoda, through *Pleurotomaria llanvirnensis* and *Ophileta* or *Raphistoma, first appear in Britain in the Upper Arenigs of* St. David's. We have no record of any Pelecypoda through the whole of the Arenig group in South Wales; but 4 species (*Palæarca amygdalus, Redonia anglica, Ribieria complanata*, and *Ctenodonta*), are known from the Stiperstones area in Shropshire, and 2 (*Palæarca socialis* and *Ctenodonta*) from Ty-obry in North Wales. The value of this upper division of the Arenig group in South Wales is enhanced by its resemblance to Barrande's Etage D 1 (Bohemia), and its close relation to the fauna found in the Arenig slates in North-West France. The recognised presence of this stage in Britain enables us to correlate our beds with those on the Continent, and thus establish a general succession for the Western European and British rocks of this age.

Sequence of the Arenig Rocks.—The sequence of the Arenig group at St. David's and North Wales is perfect, there being no evidence of any important physical changes having taken place through or during the period or epoch in which the whole series was deposited. The three divisions of *lower*, *middle*, and *upper* are characterised by a distinctive fauna, few species being common to all the three groups or divisions, but a general facies pervades the whole.

Research at Portmadoc, the Ffestiniog area, and west of the Arenigs exhibits the following upward succession :—

Arenig beds	6. Volcanic ash and tuffs interstratified with blue-black fine slate.	No fossils.
	5. Ty-obry beds. (Dark fine-grained slates.)	*Æglina, Asaphus Calymene, Trinucleus, Dionide*, and *Dendrograptus.*
	4. Thick band of grit dividing the two series. (North Wales only.)	
Tremadoc beds	3. Garth beds. (Dark slates with *Asaphus*, &c.)	*Asaphus Homfrayi, Ogygia scutatrix, Angelina, Conularia*, and *Dendroid Graptolites*, in the Arenig area.
	2. Lower Tremadoc. (Iron-stained slates and flags.)	*Niobe, Nesuretus Conocoryphe*, &c.
	1. Lingula flags. (Black slates with *Olenus*.)	

With the exception of the grit bed No. 4, the sequence in North Wales is the same as that of St. David's, this divisional rock not occurring on the St. David's Promontory.

Fauna of the Arenig Rocks.—The Arenigs of Shropshire closely resemble those of North Wales, and we cannot doubt that *the Stiperstones west of the Longmynds* are the equivalents of the "Grits," or fourth series (named above) in North Wales. They rest upon black slates of Lingula flag age, and are succeeded by a fauna which can only be correlated with the upper Arenig of the Menevian promontory, and the Ty-obry beds near Portmadoc. In North Wales 30 species occur; west of the Stiperstones, 33; and in South Wales, no less than 98. Ten species are common to the North Welsh and Shropshire area; 9 species unite the North and South Wales Arenigs; and 3 species are common to or unite all these groups and areas, viz., *Diplograptus pristis*, *Didymograptus hirundo*, and *Calymene parvifrons*.

The Crustacea (Trilobita) essentially Arenig in North Wales are *Calymene parvifrons*, *Ogygia selwynii*, *Æglina caliginosa*, and *Dionide atra*. The Rhabdophora are *Dendrograptus furcatulus*, *Diplograptus pristis*, *D. dentatus*, *D. mucronatus*, *Climacograptus tertiusculus*, *T. bicornis*, *Didymograptus geminus*, *D. hirundo*, and *Dicranograptus ramosus;* and the Pteropoda through *Conularia corium*, *C. margaritifera*, and *Theca vaginula*.

Carefully constructed tables, prepared for the purpose of testing the value of the Arenig group and its relation to the Tremadoc below and Llandeilo above, clearly show that it stands almost alone; for of the 55 known species of Rhabdophora in the Arenig, only 2 species pass to the Llandeilo (*Didymograptus Murchisoni* and *Climacograptus confertus*). The first appearance and abundance of these Graptolites in the Arenig rocks would justify the position now assigned to them as the base of the Lower Silurian rocks; only one genus (*Dendrograptus*) is known to occur in the Tremadoc group, from the Shineton shales of Shropshire. The Trilobite or crustacean fauna is equally conclusive; for out of 50 Arenig forms known, only 2 (*Trinucleus Ramsayi* and *Homalonotus bisulcatus*) unite the Arenig and Llandeilo.

The value of the Arenig group is still more apparent when we consider the development of life that accompanied those physical conditions and changes which took place at the close of the Lingula flags and Tremadoc epoch. *No less than 40 genera make their first appearance in the Arenig rocks in the British Islands.* These 40 genera belong to the following 6 classes:—

Hydrozoa, 16:—*Callograptus*, *Dendrograptus*, *Phyllograptus*, *Didymograptus*, *Azygograptus*, *Ptilograptus*, *Trigonograptus*, *Tetragraptus*, *Climacograptus*, *Nemagraptus*, *Dicellograptus*, *Clematograptus*, *Diplograptus*, *Glossograptus*, *Dichograptus*, and *Loganograptus*.

Annelida, 4:—*Helmintholithes*, *Stella-scolites*, *Nereites*, and *Palæochorda*.

Crustacea, 11:—*Æglina*, *Trinucleus*, *Barrandia*, *Calymene*, *Phacops*, *Placoparia*, *Illænus*, *Illænopsis*, *Homalonotus*, *Beyrichia*, and *Caryocaris*.

Brachiopoda, 2:—*Dinobolus* and *Siphonotreta*.

Pelecypoda (Lamellibranchiata), 2 :—*Ribieria* and *Redonia*.
Gasteropoda, 3 :—*Ophileta*, *Pleurotomaria*, and *Rhaphistoma*.

The succeeding Llandeilo, as we shall see, was equally prolific, no fewer than 48 new genera also accompanying the complete change of conditions at the close of the Arenig period and commencement of the Llandeilo.

The total number of species found in these rocks at St. David's is 70. The Lower Arenig has yielded 16 species, the middle 24, and the upper 33. Fourteen species are peculiar or confined to the lower series, 21 to the middle, and 30 to the upper. No species out of the 70 occurs in all three divisions. We thus see how distinctive a group of fossils each subdivision contains. The areas where the Arenig rocks are typically developed are :—

1. *Westmoreland:* Skiddaw.
2. *Shropshire:* Shelve area.
3. *North Wales:* Tremadoc, Tai-hirion, &c.
4. *South Wales:* Ramsey Island and St. David's area.

The following are the chief localities for fossils (18) comprised in the above four areas :—

1. *Westmoreland:* Skiddaw, Longside, Keswick, Outerside, Scaafel, Whiteside, and Braithwaite river.
2. *Shropshire:* Shelve area (west of Stiperstones), Mytton Dingle, Perkins Beech.
3. *North Wales:* Tremadoc, Garth, Ty-obry, Tai-hirion.
4. *South Wales:* Ramsey Island, Llanvirn, Whitesand Bay, St. David's,

Palæontology of the Arenig Group.

Hydrozoa.—Subsequent to the change of conditions which terminated the Tremadoc period, or at the coming in or commencement of the Arenig deposits, no less than 18 genera and 42 species of Hydrozoa first appeared in the British Arenig sea, and that without any previously existing Cœlenterate fauna being known. We have no clue to the area or region from whence they migrated; possibly Canada may be selected as one, at least, of the probable areas for their origin and dispersion. We regard the Quebec group of rocks as the equivalent in time of our Arenig series, and they contain the same species of Graptolites in great profusion. We cannot look to Scandinavia for such an assemblage; and although the Bohemian Graptolitic fauna was extensive, still, on the whole, we should, through certain genera and species, regard the Canadian area as being the source of dispersion and migration. There is intimate agreement between the faunas of many of the American and our own Palæozoic rocks; and this is notably the case with the Arenig and its Graptolites.

Thirteen genera and 28 species of Rhabdophora occur in the Skiddaw group, showing that more than two-thirds of the known genera and species are in the almost barren slates of the Keswick area; for, with the exception of 10 forms of Annelida (all tracks and burrows), 9

species of Crustacea, and 2 Brachiopoda, no others are known—neither Pelecypod, Gasteropod, Pteropod, or Heteropod, so far as we know, ever having appeared in the Skiddaw or Arenig series west of the Stiperstones in the Shelve area.[1]

The St. David's Arenigs have yielded about 8 genera and 18 species of Graptolites. Only 3 species are common to North and South Wales, namely, *Diplograptus dentatus?*, *Climacograptus confertus* and *Glossograptus ciliatus;* 6 show the relation of the Skiddaw rocks with South Wales, viz., *Didymograptus affinis*, *D. bifidus*, *D. patulus*, *Tetragraptus quadribrachiatus*, *Phyllograptus typus*, and *Diplograptus dentatus?;* and 7 are common to the Stiperstones area and South Wales, viz., *Didymograptus patulus*, *D. affinis*, *D. hirundo*, *D. bifidus*, *Diplograptus dentatus*, *Clematograptus implicatus*, and *Climacograptus confertus*. Out of the *entire* Arenig Rhabdophora, only 2 or 3 genera and species pass to the succeeding Llandeilo rocks.

Annelida.—Nine genera and 11 species are described, but they possess no zoological value, being simply worm-burrows, worm-tracks, or trails of Mollusca.

Crustacea.—The Arenig rocks have distributed through them 14 genera of Trilobites and 48 species. No group in the British rocks is so specialised as the Arenig Crustacea. The Skiddaw rocks have yielded 9 species, representing 7 genera;[2] the Shelve Arenigs 10 species and 7 genera.[3] The Northern or Skiddaw fauna is allied to the Shelve or Shropshire group through 3 species, *Agnostus Morei*, *Ogygia Selwynii*, and *Æglina binodosa*. The *special* Skiddaw forms are *Caryocaris Wrightii*, *Phacops Nicholsoni*, *Niobe Doveri*, and *Æglina* sp. The *special* Shelve species are *Trinucleus Murchisoni*, *Illænus perovalis*, *I. Thomsoni*, and *Cheirurus* sp. The *special* North Wales species are *Asaphus affinis* and *Caryocaris Marrii*. Those special to South Wales are *Agnostus hirundo*, *Asaphus Homfrayi*, *Ogygia scutatrix*, *O. peltata*, *O. bullina*, *Asaphus menapiæ*, *Trinucleus Sedgwickii*, *Ampyx Salteri*, *Æglina boia*, *Æ. grandis*, *Æ. obtusicaudata*, *Barrandia Homfrayi*, *Calymene ultima*, and *C. vexata;* the occurrences in South Wales, however, are 15 genera and 35 species. Eleven new genera of Crustacea (10 of which are Trilobita) appeared in the Arenig sea: they are *Æglina*, *Angelina*, *Trinucleus*, *Barrandia*, *Calymene*, *Phacops*, *Placoparia*, *Illænus*, *Illænopsis*, *Homalonotus*, and the Phyllopod *Caryocaris*, which, with *Placoparia*, never passed to higher rocks.

Brachiopoda.—*Lingulella*, *Lingula*, *Orthis*, *Obolella*, *Discina*, *Siphonotreta*, and *Dinobolus*, represented by only 18 species, are all that can be recorded of this class. All the genera and 12 of the 18 species occur in the St. David's area. *Lingula attenuata*, *Orthis alata*,

[1] Lord's Hill, Bog Mine, Dingle, Ritton Castle, Corndon, &c.

[2] *Caryocaris Wrightii*, *Agnostus Morei*, *Ogygia Selwynii*, *Trinucleus Gibbsii*, *Æglina caliginosa* (Salt.), *Æ. binodosa*, *Æ.* sp., *Phacops Nicholsoni*, and *Niobe Doveri*.

[3] *Agnostus Morei*, *Ogygia Selwynii*, *Trinucleus Murchisoni*, *Æglina binodosa*, *Calymene parvifrons* and var. *Murchisoni*, *Illænus perovalis*, *I. Thomsoni*, *Cheirurus Frederici*, and *C. pectinatus*.

O. calligrama, *O. striatula*, and *Obolella plumbea* occur west of the Stiperstones. The five North Wales forms are *Lingulella Davisii*, *L. lepis*, *Orthis lenticularis*, *O. calligramma*, and *Obolella plicata*. *Lingula petalon*, *L. brevis*, and *Orthis calligramma* pass to the Llandeilo rocks; the special forms are only 6—*Siphonotreta micula*, *Dinobolus Hicksii*, *Discina* sp., *Orthis striatula*, *O. remota*, and *O. alata*. The new genera are *Dinobolus* and *Siphonotreta*.

Pelecypoda (Lamellibranchiata).—*Ribieria complanata*, *Modiolopsis trapeziformis*, *Palæarca amygdalus*, and *Redonia anglica* occur in the Shelve Arenigs. None are known either in the Skiddaw rocks or in South Wales, 6 species being the entire bivalve fauna. *Ribieria* and *Redonia* first appear in the Arenig rocks.

Gasteropoda.—Only 4 genera and 4 species are at present known. *Pleurotomaria llanvirnensis* and *Ophileta* sp., occur at Llanvirn, St. David's; *Rhaphistoma*, Skiddaw only; and the Stiperstone form is *Euomphalus corndensis*. No species known in North Wales.

Pteropoda.—*Conularia* and *Theca*, each with 4 species, constitute the Arenig Pteropod fauna. The Shelve species are *Theca simplex* and *T. vaginula*. Those occurring in North Wales are *Theca vaginula*, *Conularia corium*, and *C. margaritifera*. *Theca Harknessi*, *T. caereesiensis*, *Conularia llanvirnensis*, and *C. Homfrayi* range through the St. David's Arenigs.

Heteropoda.—Four species of *Bellerophon* occur in the Stiperstone beds and 2 in the St. David's; these are all that are known. They are *B. hippopus* (Salt.), *B. bilobatus*, *B. carinarioides*, and *B. perturbatus*. The South Wales species are *B. multistriatus* and *B. llanvirnensis*. No species known in North Wales.

Cephalopoda.—*Orthoceras Avelinii* and *O. encrinale* occur in the Corndon area (Shropshire). *O. sericeum* and *caereesiense* are only known at St. David's, South Wales; none in the Skiddaw beds.

Distinctness of the Arenig Fauna.—The distinctive value of the Arenig fauna is shown by the fact that only 8 genera and 9 species pass to the Llandeilo; and 4 of these are Hydrozoa, 2 are Crustacea (*Trinucleus Ramsayi* and *Homalonotus bisulcatus*), and 3 Brachiopoda (*Lingula brevis*, *L. attenuata*, and *Orthis calligramma*). Looking, therefore, at the number of genera (63) and species (150) in the whole Arenig series, the change or extinction at the close of the period has scarcely any parallel in the Palæozoic rocks. Only 8 genera and 9 species transgressed or passed to the succeeding formations; and 11 genera and 16 species came in with the advent of the group from the Lower Cambrian series. The true numerical faunal value of the Arenig group is, therefore, 51 genera and 133 species; the 9 species which pass to higher formations do not affect the Arenig fauna beyond linking it to the next group in succession.

TABLE VIII.

Distribution and Comparison between the Arenig Species of St. David's in South Wales and those of North Wales, the Stiperstones in Shropshire, and Skiddaw in Westmoreland.

The entire fauna of the St. David's Arenig rocks comprises 88 species.
" " Arenigs of North Wales 27 "
" " Stiperstones area 41 "
" " Skiddaw slates 70 "

The whole Arenig fauna comprises 181 species.

Classes.	St. David's, South Wales.	North Wales.	Stiperstones, Shropshire.	Skiddaw, Westmoreland.
1. Hydrozoa occurring in	34	5	11	48
2. Annelida . . .	...	...	1	10
3. Crustacea . . .	31	11	10	10
4. Brachiopoda . .	13	5	6	1
5. Pelecypoda . .	...	2	4	...
6. Gasteropoda . .	2	...	1	1
7. Pteropoda . . .	4	3	2	...
8. Heteropoda . .	2	...	4	...
9. Cephalopoda . .	2	1	2	...
	88	27	41	70

The following groups of strata, in ascending order, occur in succession in the so-called "Lake" district.

They may not all occur in one area, but throughout the Lake district it is the recognised order or succession :—

Silurian . .	No. 7.	The Kendal rocks = Ludlow series.
	" 6. "	Coniston grits.
	" 5. "	Coniston flags.
Upper Cambrian	" 4. "	Graptolitic mudstones.
	" 3. "	Coniston limestone and shales = Caradoc or Bala.
	" 2. "	Borrowdale series, or green slates and porphyries.
	" 1. "	Skiddaw slates (Arenig).

Borrowdale Series, or Green Slates and Porphyries.

This great series of rocks was termed by Sedgwick the "*Green* Slates and Porphyries," and the name "Borrowdale rocks" was proposed for them by Professors Harkness and Nicholson.

These rocks essentially consist of a vast succession of bedded porphyries, with stratified felspathic ashes and breccias. The whole mass appears to be made up of volcanic material. The old name given by Professor Sedgwick, while applicable to a part of the group, does not represent the character of the whole, hence the adoption of the geographical name "Borrowdale" series, or volcanic series of Borrowdale. Whether the volcanic rocks of this series were subaerial, or poured

out over the sea-bed, and the ashes subjected to the triturating or sorting action of the water, is still an open question. Near the summit of the Borrowdale series there occurs a thin group of ashy beds containing fossils. They underlie the Coniston limestone or Bala series, and are separated from it by a mass of lava. Consequently the fossiliferous beds belong to the green slates and porphyries. Amongst the fossils are *Petraia sub-duplicata*, *Calymene Blumenbachii*, *Orthis vespertilio*, *O. flabellulum*, and *Strophomena tenuistriata*.

The upper portion, therefore, of the Borrowdale series must be referred to the Caradoc or Bala period.

Dufton Shales.—Beneath the Pennine chain, and underlying the Coniston limestone, there occurs a remarkable and well-marked series of fossiliferous shales, &c., termed by Professor Harkness the "Dufton shales," replete with undoubted Bala fossils. Their stratigraphical position, however, is not so certain; they are well developed in the Silurian area, which includes the Cross Fell range. They correspond to the thin fossiliferous beds at the summit of the Borrowdale series.[1]

The "Swindale Shales," of Swindale Beck, near Knock, are below the Dufton shales, and belong to the Green slate series. All evidence seems to show that the entire Borrowdale series, or the group of the green slates and porphyries, is of the age of the Caradoc beds of Wales.

The fossils of the Dufton shales are characteristic Bala types, and the entire deposit forms palæontologically the base of the Coniston limestone.

ACTINOZOA.—*Petraia* sp., *Chætetes* sp.
ANNELIDA.—*Conchicolites gregarius.*
BRACHIOPODA.—*Leptæna transversalis*, *L. sericea*, *Strophomena expansa*, *S. rhomboidalis*, *Orthis testudinaria*, *O. biforata*, *O. vespertilio*, *Discina corona*, and *Lingula tenuigranulata.*
HETEROPODA.—*Bellerophon bilobatus.*
CRUSTACEA.—*Calymene Blumenbachii*, *Trinucleus concentricus*, *Cybele verrucosa*, *Ampyx nudus*, *Lichas laxatus*, *Illænus Bowmanni*, *Encrinurus* sp., *Beyrichia Wilckensiana*, and *Primitia semicircularis.*
CEPHALOPODA.—*Orthoceras* sp., *Orcoceras* sp.

The predominance of the Brachiopoda, together with the Crustacea in the Dufton shales, leaves no room for any doubt as to their age; and there is no break in continuity between the shales and the underlying Borrowdale rocks.

The Pusgill shales contain a similar fauna, differing only in a few additional species. These are *Stenopora fibrosa*, *Lingula ovata*, *Orthis calligrama*, *O. alternata*, *Modiolopsis orbicularis*, *Tentaculites annulatus*, *Homalonotus bisulcatus*, *Ampyx mammillatus* and *Orthoceras Brongniartii.*

Sequence in the Lake District.—Mr. Ward, in his memoir upon the "Geology of the Northern Part of the English Lake Dis-

[1] They occur in four chief exposures, viz., Swindale Beck, near Knock; Pus Gill and Dufton Town Dykes, near Dufton; Harthwaite Gill, near Kirsley; and at the smelt-mill, near Hilton.

trict,"[1] estimates that 12,000 or 15,000 feet is not too high a maximum for the thickness of this volcanic series. The following is the general sequence of this group and the Skiddaw slates as a whole in descending order:—

Volcanic Series, about 12,000 feet.	9. Bedded fine flinty ash of Great End, Esk Pike, and Allen Crags.
	8. Unbedded coarse ash and breccia of Broad Crag and Long Pike.
	7. Bedded and rough ash of Scafel Pikes, Glaramara, and Allscarf.
	6. Partially bedded fine flinty ash of Base Brown and Rosthwaite Fell.
	5. Well-bedded ash of Scathwaite.
	4. Contemporaneous traps of Watendlath Fell, High Scat, and Bleaberry Fell.
	3. Breccia and bedded ash of Brund Fell and Watendlath.
	2. Contemporaneous traps of Honister, Dale Head, Gate Crag, and Falcon Crag.
	1. Purple breccia ash and some contemporaneous trap.
Transition Beds.	Interbedded volcanic strata and Skiddaw slate.
Skiddaw Slate, 10,000 to 12,000 feet.	5. Black slates of Skiddaw.
	4. Gritty beds of Gatesgarth (Buttermere), Latterbarrow (101 S.W.), Tongue Beck (Skiddaw), Watch Hill, and Great Cockup (101 N.E.)
	3. Dark slates.
	2. Sandstone series of Grasmoor and Whiteside.
	1. Dark slates of Kirkstile, between Loweswater and Crummock.[2]

Judging mainly from the sequence of lithological divisions as compared with those of North Wales,

No. 5 may be regarded as Arenig (Upper Arenig of Hicks).
No. 4 as the Carnarvonshire Grit and Stiperstones (the Middle Arenig of Hicks).
No. 3 as Tremadoc.
No. 2 } as Lingula flags.
No. 1 }

Should subsequent research prove this to be correct, the period represented in Wales by the Aran and Arenig volcanic beds, the Llandeilo slates, and the Snowdon volcanic series is represented in Cumberland by one continuous volcanic formation.

In Wales the Bala limestone forms the top of the series.
In Cumberland, the Coniston limestone.

The nature of the Skiddaw deposits, and the character of the fauna contained, point to marine conditions accumulated in a more or less shallow sea, and in the absence of limestone beds. We must not, however, infer that the present known fossil remains represent the full life of the period, which under more favourable conditions may have been as abundant and plentiful as in more modern seas.

Relation to Volcanic Rocks.—The unconformity of the Coniston limestone and overlying beds to the "*volcanic series*" admits of no doubt, and this probably represents *the time* during which the *volcanic land area* was being depressed beneath the Coniston limestone and

[1] Memoirs of the Geological Survey. "Geology of the North Part of the English Lake District," with Appendix by R. Etheridge.
[2] Ward, *loc. cit.*, pp. 46–47.

Upper Silurian sea. Then over the whole district, during very long periods, there were deposited upon the series of volcanic strata a great thickness of Upper Silurian rocks, which has been estimated in the Kendal area at no less than 14,000 feet. Thus, at the close of the Upper Silurian period, there is every reason to believe that in the northern part of the present Lake District the Skiddaw slates were buried deeply beneath the whole of the volcanic series (from 12,000 to 15,000 feet in thickness), and the Upper Silurian strata (probably 14,000 feet), making together some 25,000 to 30,000 feet of strata above the topmost beds of the Skiddaw series. This amount of marine sedimentary or deposited matter has been removed through the agency of denudation, both marine and sub-aerial or meteoric.

CHAPTER IX.

LOWER BALA AND LLANDEILO FLAGS.

Lower Bala and Llandeilo Flags.

Schistes with Graptolithus Colonus.
Schistes Ardoisiers, with Calymene Tristani (D'Anger, Cherbourg, Falaise, &c.) (France.)
Etage D. 2, Quartzite du Drabow. (Barrande, Bohemia.)
Regio C. Asaphorum Calcaire d'Oeland. (Angelin, Scandinavia.)
Champlain Division. { *Trenton Limestone,* / *Black River Limestone.* } (North America.)

THE three classical localities for the Llandeilo rocks and fossils are Llandeilo, Builth, and Abereiddy Bay, north of St. David's. Each of these areas possesses a characteristic and definite fauna. For although, on the whole, the species in each locality are much the same, still the facies is peculiar in each.

It is of interest to clearly understand the true position of the great band of dark roofing-slate of the "Ffestiniog quarries," &c., that underlies the Caradoc or Bala series, occupying the position of the Llandeilo flags. "It is probable that the lowest portion of the Llandeilo group may occur in the Arenig and Ffestiniog mountains, and also in the Arrans," but the evidence is slight and the materials (in the shape of fossils) are scanty. *Bellerophon perturbatus* has been obtained in dark slates near Bangor, and also other fossils identical with those of the Llandeilo rocks, "which overlie the Arenig porphyries." It is doubtful, however, if the black slates of Anglesey are the equivalents of the dark earthy slates that range east of the Arenig mountain. The Anglesey slates contain *Asaphus Powisii* and *Phacops apiculatus*, both rare in the Llandeilo group.

The Llandeilo rocks and their fossils in North Wales are confined

to few localities, and are but feebly exposed anywhere; and the whole fauna of this formation in that area numbers 47 species. Eighteen of these belong to the prolific class Brachiopoda, and 15 to the Crustacea. The Llandeilo rocks of South Wales contain 88 species, and about 40 are common to North and South Wales. It is important to show those species which unite the two areas; but for our purpose we name only the Crustacea (Trilobita), Hydrozoa, and Brachiopoda. Of the first class eight species are common, viz., *Asaphus tyrannus, A. Powisii, Ogygia Portlockii, Calymene cambrensis, C. Blumenbachii, Trinucleus concentricus, T. favus,* and the ostracode *Beyrichia complicata.*

The Hydrozoa are not less important; they are *Diplograptus foliaceus, D. dentatus, Didymograptus Murchisoni, Leptograptus flaccidus, Dicranograptus ramosus, D. formosus, D. Nicholsoni, Climacograptus bicornis, C. cælatus, C. confertus, C. Sharenbergi,* and *Dicellograptus sextans.*

The Brachiopoda number still more, as we should expect from their habit and relation to the sea-beds upon which they lived. They are all common and well-known species, and 8 of the 13 forms belong to the genus *Orthis,* viz., *Orthis vespertilio, O. turgida, O. Actoniæ, O. calligramma, O. striatula, O. elegantula, O. insularis, O. biforatus, Strophomena rhomboidalis, Leptæna tenuissimistriata, L. sericea, Crania divaricata,* and *Siphonotreta micula.*

The whole Llandeilo fauna in the British Islands numbers 80 genera and 175 species; of these, Ireland has yielded 51 species, Scotland 66, and Shropshire only 26; these latter are chiefly from the Shelve district, and are mostly Crustacea and Brachiopoda.

St. David's Area.—In the St. David's area and throughout Pembrokeshire, Breconshire, and Caermarthenshire, the typical localities of Llandeilo and Builth, &c., contain a special fauna. At Abereiddy Bay the black slates and argillaceous limestones are interstratified with felspathic tuff, and are about 2500 feet thick. They rest upon the Arenig group, which possesses a distinct fauna; a thick bed of tuff divides them. The immediate presence and abundance of *Didymograptus Murchisoni, Dicellograptus,* and *Cryptograptus,* &c., in the slates on the south side of Abereiddy Bay above the felspathic tuff, at once clearly marks the base of the Llandeilo beds.

Fauna of the Llandeilo Series.—The Llandeilo series of St. David's is divided into three sub-groups,[1] the lowest containing Rhabdophora or Graptolites, associated with *Trinucleus Ramsayi, Calymene Murchisoni,* and *Theca caeresiensis,* which especially characterise this flaggy division. The *middle* sub-group consists of dark "calcareous shales, with compact limestone at the upper part;" *Asaphus tyrannus, A. peltastes, Calymene cambrensis, Ogygia convexa, Trinucleus fimbriatus, T. Lloydii,* and *Lichas patriarchus,* are the typical Crustacea, with *Lingula granulata, Halysites catenulatus,* and six species of Graptolites. In addition to the fauna, the calcareous nature of the beds lithologically separates this *middle* sub-group from

[1] Quart. Journ. Geol. Soc., vol. xxxi. pp. 177–180.

the over- and under-lying series. Everywhere it is characterised by the forms just enumerated; many of the same species occur at Llandewi Velfrey, Lampeter Velfrey, and Musclewick Bay. The Upper Llandeilo is also distinguished by special forms of Trilobita—*Barrandia Cordai*, *B. longifrons*, *Cheirurus Sedgwickii*, *Ogygia Buchii*, *Calymene duplicata*, *Ampyx nudus*, *Agnostus M'Coyi*, and by *Lingula Ramsayi*. It will thus be seen that each division is specialised or can be discriminated by its Crustacea; the well-known *Ogygia Buchii* and *Cheirurus Sedgwickii* are here, as elsewhere, the typical forms in the upper black argillaceous slaty flaggy sandstones. The middle series yields *Asaphus tyrannus*, *A. peltastes*, and *Ogygia convexa*, &c.; and the lower *Calymene Murchisoni* and *Trinucleus Ramsayi;* and this grouping holds good wherever the Llandeilo beds occur.[1] Three species only of Trilobita have occurred in the Scotch Llandeilo rocks, viz., *Illænus Bowmannii*, *Salteria involuta*, and *S. primæva*. Ireland has yielded five species: these are—*Acidaspis Jamesii*, *Ampyx mammillatus*, *Ogygia Portlockii*, *Phacops truncatocaudatus*, and *Æglina mirabilis*.

The elaborate researches of Mr. Lapworth in Scotland into the history of the Rhabdophora of that and other areas has greatly modified our views respecting their distribution and range.

The Moffat or Scotch Graptolite Shales.—The oldest fossiliferous strata known in Scotland are the Graptolite shales forming the well-known Moffat series, a group of black shales about 600 feet thick, and separated by Mr. Lapworth into three distinct palæontological divisions.[2] The lowest (Lower Moffat or Glenkiln Shales) he determines to be of Upper Llandeilo age; the Middle Moffat or Hartfell Shales above, he correlates with the Bala group of North Wales "as an attenuated representative;" and the third or uppermost (the Upper Moffat or Birkhill Shales) represents the Lower Llandovery. This last determination has an important bearing upon the distribution of the Graptolithina or Rhabdophora, it being well known that in the Llandovery rocks of Wales no Graptolites occur. The Lower Llandovery of Cardigan and Merioneth, of such great thickness and extent (yet without Graptolites), has "dwindled down to the thickness of the Birkhill Shales (about 70 feet) in the intervening Lake district, where it constitutes the Coniston Mudstones —a group of beds almost identical in thickness, lithology, and palæontology with the equivalent Scottish deposit of the Birkhill Shales."

[1] 1. The Lower Llandeilo in Abereiddy Bay, yields 22 species.
2. „ Middle „ „ „ 27 „
3. „ Upper „ „ „ 23 „

And only four species (*Diplograptus foliaceus*, *D. tricornis*, *Climacograptus scalaris*, and *Bellerophon perturbatus*), out of the 57 known forms, are common to, or unite the three horizons.

[2] The Graptolites of the Moffat Series, by C. Lapworth, F.G.S., Quart. Journ. Geol. Soc., vol. xxxiv. pp. 240–343. In this exhaustive paper the general characters of the Lower Silurian rocks of Scotland and the strata of the Moffat district are ably discussed.

The Llandeilo age of the Lower Moffat shales is determined through the total absence of those complex Arenig forms of "*Dichograpti, Tetragrapti*, and *Phyllograpti*, so characteristic a feature of the Graptolithic fauna of the Skiddaw, Shelve, St. David's, and Canadian equivalents."

Zones of the Scotch Rhabdophora.—"Arranging the Moffat strata in the order in which they are displayed, and distinguishing each chief band by its peculiar fossil," we have the following:[1]—

Sections or Groupings for the Lower Llandovery, Bala, and Upper Llandeilo (Graptolithic) Series.

III. Birkhill Shales.	Upper Birkhill or Grey Shale group.	Zone of *Rastrites peregrinus.*	Lower Llandovery.
		Zone of *Monograptus spinigerus.*	
		Subzone of *Diplograptus cometa.*	
	Lower Birkhill or Black Shale group.	Zone of *Monograptus gregarius.*	
		Zone of *Diplograptus vesiculosus.*	
		Zone of *Diplograptus acuminatus.*	
II. Hartfell Shales.	Upper Hartfell or Barren Mudstone group.	Zone of *Dicellograptus anceps.*	Bala.
		Zone of Barren Mudstones.	
	Lower Hartfell or Black Shale group.	Zone of *Pleurograptus linearis.*	
		Zone of *Dicranograptus Clingani.*	
		Zone of *Climacograptus Wilsoni.*	
I. Glenkiln Shales.	Upper Glenkiln Shales.	*Didymograptus* beds.	Upper Llandeilo.
	Lower Glenkiln Shales.	Ribbed mudstones.	

"All evidence tends to prove that the Glenkiln shales belong to the age of the Upper Llandeilo series, and are closely allied to the North-Wales grouping." The absence of certain *Didymograpti* and *Phyllograpti* from the Glenkiln division, and their abundance in the lower beds of the Llandeilo of Wales and Sweden, oblige us to assign the Scotch Glenkiln Rhabdophora "to the highest division of the Llandeilo, and not far below the base of the Caradoc or Bala."

The Hydrozoa, Crustacea, and Brachiopoda alone constitute 123 out of the 175 known species of which the mass of the fauna of the Llandeilo is composed. The same classes largely transmit their genera and species to the succeeding Caradoc or Bala rocks, viz., 16 species of Hydrozoa, 17 Crustacea, and 23 Brachiopoda, or, together, 56 out of the whole 76 that connect the two formations. It is interesting to know those areas that are specially most prolific in the above groups; they help us to draw conclusions as to the nature of the sea-bed and its bathymetrical condition during the time of the deposition of the Llandeilo series and succeeding Caradoc, which are more intimately related than is generally believed. United, the Llandeilo fauna of North and South Wales contains 94 species. This is the known number for Wales, 88 occurring in South and 47 in North Wales, 41 being common to both areas, and this chiefly through the Hydrozoa and Crustacea. Upon whatever hypothesis we may account for the

[1] Lapworth, *loc. cit.*

physical relationship between the Llandeilo rocks of Scotland and Ireland, the connecting species are few (only 27); and no Crustacea are common to these two countries, which, out of a total fauna of 45 species, is remarkable.

Palæontology of the Llandeilo Rocks.

Plantæ.—None.

Protozoa.—*Ischadites antiquus.* No other Protozoon has been recognised in the Llandeilo rocks.

Hydrozoa.—The Llandeilo beds of Scotland appear to be the most prolific in Rhabdophora. Our knowledge of them is due to the researches of Nicholson, Lapworth, Carruthers, and Hopkinson. Forty-four species illustrate 18 genera; but it is chiefly through the larger genera that this Graptolithic fauna is represented. South Wales is poor as compared with Scotland, having only 18 species, or about half the number. North Wales has yielded 7 species, and Ireland 28. *Didymograptus, Diplograptus, Climacograptus,* and *Dicellograptus* are those genera chiefly occurring in South Wales; and *Diplograptus, Dicellograptus,* and *Climacograptus* in North Wales, &c. The Llandeilo rocks of Ireland contain species of nearly all the above genera, and 16 species pass to the succeeding Caradoc.

Actinozoa.—*Halysites catenulatus, Favosites fibrosus,* and *Monticulipora favulosa,* complete the list of the Llandeilo Actinozoa. All three occur in South Wales, and *Favosites fibrosus* in Ireland. Neither Scotland nor England has any representative. All three species pass to the Caradoc. These are the *first known corals* occurring in the British rocks; but this group of the Cœlenterata expands to 20 genera and 42 species in the suceeeding Caradoc. Little limestone occurs in the Llandeilo, and that little is in the upper division. The increase of calcareous matter in the Caradoc rocks is due to life agency, and we may therefore attribute much of it to the secretion of carbonate of lime by the Cœlenterata.

Echinodermata.—We know of only four species in this class, which, like the Actinozoa, may be said to appear first in the Llandeilo. None are known in the Arenig below. The species are *Actinocrinus Wynnei, Echinosphærites granulatus, Palæasterina Kinahani,* and *Glyptocrinus basalis.* Two of these passed to the Caradoc. As with the Actinozoa, this group became greatly developed in the Caradoc, no less than 15 genera and 32 species enriching that formation. These, like the corals, must have lived in a moderately deep sea, well charged with carbonate of lime.

Crustacea.—In this class the Trilobita are of high significance, both in the Llandeilo and Caradoc formations, especially the latter, in which we know of more than 100 British species. The Llandeilo rocks have yielded 18 or 20 genera and only 45 species, or upon an average only about two species to each genus. Many genera are represented by one species only: these are *Homalonotus bisulcatus, Lichas*

patriarchus, Stygina Murchisoniæ, Cheirurus Sedgwickii, and *Acidaspis Jamesii*.

The only three Scotch Llandeilo species known are *Illænus Bowmanii, Salteria involuta*, and *S. primæva*. The Irish species are *Acidaspis Jamesii, Ampyx mammillatus, Ogygia Portlockii, Phacops truncato-caudatus, Calymene duplicata*, and *Æglina mirabilis*. The English forms are chiefly from the Shelve area, and 8 out of the 10 occur in South Wales.

The following species occupy and characterise definite areas, and are single representatives of the genera named :—

Homalonotus bisulcatus.—N. Wales.

Agnostus M'Coyi, Stygina Murchisoniæ, Cheirurus Sedgwickii, and *Lichas Patriarchus*—S. Wales ; and *Acidaspis Jamesii*—Ireland.

The following important Llandeilo forms are entirely restricted, both geographically and stratigraphically, not ranging either lower or higher :—

Illænus murchisoni, Ogygia angustissima, O. Portlockii, Asaphus tyrannus, A. peltastes, A. laticostatus, Calymene Cambrensis, Trinucleus Lloydii, T. Ramsayi, T. favus, Barrandia longifrons, B. radians, B. cordai, } South Wales.

Ogygia Portlockii, O. corndensis, O. Buckii, O. conveza, Asaphus tyrannus, Calymene Cambrensis, Trinucleus Edgelli, T. favus, Æglina major, } North Wales.

Ogygia corndensis, O. Buchii, O. conveza, Asaphus tyrannus, Calymene cambrensis, Trinucleus Lloydii, ... } England.

Salteria involuta, S. primæva.—Scotland.

Ogygia Portlockii.—Ireland.

All the above 20 species are confined to the Llandeilo and also to the geographical areas assigned to them, and they are essentially characteristic ; the remaining 15 species pass to the Caradoc, and are therefore of no value stratigraphically. To complete the analysis of the distribution of the Crustacea, we name the 15 species that connect the Llandeilo and succeeding Bala formations :—

Acidaspis Jamesii, Homalonotus bisulcatus, Illænus Bowmanni, Ampyx mammillatus, A. rostratus, A. nudus, Asaphus Powisii, Calymene duplicata, C. Blumenbachii, C. brevicapitata, Trinucleus fimbriatus, T. concentricus, Phacops apiculatus, P. truncato-caudatus, and *Æglina mirabilis*.

The singular phyllopod *Peltocaris aptychoides* occurs both in Scotland and North Wales, and is not known out of the Llandeilo beds.

Brachiopoda.—This class is an important factor in the Llandeilo rocks, 10 genera and 34 species being known. Five new genera first appear, *Acrotreta, Crania, Rhynchonella, Strophomena*, and *Leptæna*. As we should anticipate, the species are most numerous in South and North Wales. The former area gives us 26 species, the latter 18, Scotland 9, and England 6. Although there are 20 species in the Arenig group (and 34 in the Llandeilo), *yet no species is common to the two formations ;* no Arenig form passes up ; but of the 34 Llandeilo forms, 23 pass to the Caradoc. This is chiefly through the genera *Lingula, Orthis*, and *Leptæna*. We have already seen that of the whole fauna of the Arenig (150 species) only 17 pass up into the

Llandeilo, whereas no less than 72 out of the 175 Llandeilo species survive or range to the Caradoc, viz., Hydrozoa 16 species, Crustacea 17, Brachiopoda 23, Pelecypoda 3, Gasteropoda 4, Heteropoda 5, and Cephalopoda 2 species.

Pelecypoda (Lamellibranchiata).—With the exception of the Irish species, *Pleurorhynchus* (*Conocardium*) *calcis*, all the bivalve mollusca known are from the South Wales beds. We know of no Llandeilo Pelecypod mollusk either in England or Scotland. *Modiolopsis expansa*, *M. inflata*, *Ctenodonta varicosa*, and *Palæarca amygdalus* occur only in the South Wales rocks. Three pass to the Caradoc.

Gasteropoda.—South Wales has hitherto yielded only *Murchisonia simplex*; Ireland, *Euomphalus parvus* and *Turbo tritorquatus*; the Shelve area and North Wales, *Cyclonema crebristria* and *Euomphalus corndensis*; the remaining 7 being from the Durness limestone of Scotland (these may be Arenig). The Scotch species are *Euomphalus matutinus*, *Murchisonia angulocincta*, *M. angustata*, *M. bellicincta*, *M. gracilis*, *Ophileta compacta*, and *Pleurotomaria thuli*. Three pass to the Carodoc. *Euomphalus*, *Cyclonema*, and *Murchisonia* are new genera, first appearing in the Llandeilo rocks.

Pteropoda.—Three species of *Theca*—*T. cometoides* (Irish), *T. reversa*, and *T. caerecesiensis*, St. David's. We have no evidence of any species occurring in England, North Wales, or Scotland.

Heteropoda.—Scotland possesses 5 of the 7 species known; and 4 of the 5 are *Maclureæ*. These are associated with the Gasteropoda in the Durness limestone of north-west Scotland.

Cephalopoda.—Of the 3 genera and 7 species, none occur either in North Wales or Ireland. The only English species is *Orthoceras Avelani?*, from the Shelve area (Shropshire); *Endoceras eoum* is a South Wales species. The remaining species are Scotch, including the singular genus *Piloceras* (*P. invaginatum*) from the Durness limestone.

The following is an analysis of the whole Llandeilo fauna, embracing the North and South Welsh areas and Scotland, and showing its relation to the Caradoc group:—

	No. of Species.		
Protozoa	1	passes to Caradoc.	
Actinozoa	3	all pass	„
Echinodermata	4	of these 2 „	„
Annelida	9	„ confined to Llandeilo.	
Crustacea	45	„ 17 pass to Caradoc.	
Hydrozoa	44	„ 16 „	„
Brachiopoda	34	„ 23 „	„
Pelecypoda	6	„ 3 „	„
Gasteropoda	12	„ 3 „	„
Heteropoda	7	„ 4 „	„
Cephalopoda	7	„ 4 „	„
Pteropoda	3	„ 1 passes	„
	175	77	

Geographical Distribution of the Llandeilo Rocks, &c.—The geographical distribution of the Llandeilo rocks is complicated, owing to the volcanic tuffs and felspathic traps associated with the series in those areas where developed. In Shropshire, the entire group rests upon the Arenig or Stiperstone series; in North Wales, the lowest part of the Llandeilo occurs in the Arenig and Ffestiniog mountains; and in the Arrans is also conformable to the Arenig series.

The following species are typical and *confined* to the Llandeilo rocks:—*Homalonotus Vulcanii, Barrandia cordai, Asaphus tyrannus, Calymene cambrensis, C. murchisoni, Trinucleus Lloydi, T. Ramsayi, Ogygia Buchii, O. Portlockii, Stygina murchisoni*, and *Cheirurus Sedgwickii*.

No less than 47 genera first appeared in the Llandeilo sea, or were not known in the previous Arenig or Tremadoc rocks. Their analysis is as follows:—In the class *Amorphozoa*, 1 genus; *Hydrozoa*, 9; *Actinozoa*, 4; *Annelida*, 6; *Echinodermata*, 3; *Crustacea*, 9; *Brachiopoda*, 5; *Pelecypoda*, 8; and *Cephalopoda*, 2 = 47 genera.

CHAPTER X.

CARADOC SANDSTONE, BALA BEDS, AND CONISTON LIMESTONE.

Caradoc or Bala.

Caradoc Sandstone and Upper Bala beds = (Utica slate.)
Grès de May. (Calvados.)
de Gahard. (Bretagne, &c., France.)
Etage D. 4 (Barrande, Bohemia), and *Etage D.* 3 (Barrande.)
Regio D. Trinucleorum. (Angelin.)
Schistes de Westrogothie Bornholme. (Scandinavia.)
Hudson River group. (America.)

History.—These rocks overlie the Arenig and Llandeilo groups, and underlie the May Hill sandstone. The facies of the fauna is that of the Llandeilo, but greatly extended or developed. The difference in the fossil contents of the two groups is due chiefly to age and the conditions under which they were deposited. Sedgwick, in 1853, places the Bala group in his "Upper Cambrian," dividing it into Lower, Middle, and Upper Bala. It includes also the Cambro-Silurian of some authors.

Sir Roderick Murchison, in 1833, first noticed the "Caradoc Sandstone,"[1] and in 1834 the same rocks were described by him under the name of the "Horderley and May Hill Sandstone." In the "Silurian System," subsequently published, these strata were called "Caradoc Sandstone," the name being based upon their being highly developed in the neighbourhood of Caer Caradoc, near Church

[1] Proceedings of the Geological Society, 1833, vol. i. p. 476.

Stretton. The term "Bala" was applied by Professor Sedgwick, to certain rocks around the town of Bala in Merioneth. They form the upper part of the Caradoc of the Geological Survey. The typical Bala series are best developed between Dinas-Mowddwy, Bettws-gwerfulgoch, and Bettws-y-coed.

In the early history of the Caradoc rocks the fossils of the *Pentamerus* beds were included in its lists. The fossils of the May Hill or upper group, however, are very distinct from those of the Caradoc Sandstone. Again, the Upper *Pentamerus* beds rest unconformably on the true Caradoc Sandstone, and the whole pass under the Wenlock Shale. In Shropshire and at Builth the unconformity is visible; and in the Malvern area, west of the Herefordshire and Worcestershire Beacons, the Upper Llandovery or May Hill beds lie directly, but unconformably, upon the Upper Lingula flags or "*Dictyonema* Shales." Again, the Upper Llandovery beds on the banks of the Onny river lie on the upper part of the Caradoc or Bala beds. West of Wenlock Edge they cover the nearly vertical edge of the Cambrian or Longmynd rocks. "Probably, there is no unconformity so complete yet observed in other members of the British Silurian strata." The tabular results appended, relative to the distribution of the Caradoc fossils both in time and space, embody almost all the existing information on the subject. The result, however, will be referred to here, as being a complete analysis of the 600 known species.

Woodwardian Collection and Catalogue.—In the catalogue of the Cambrian and Silurian fossils in the Woodwardian Museum, Cambridge,[1] Prof. Sedgwick has divided the Bala beds into three subgroups, placing them in his Upper Cambrian stage (the Cambro-Silurian of some authors, the Lower Silurian of Murchison). The grouping adopted in this catalogue is such as to eliminate the true Llandeilo fossils and place them in the Lower Bala group. The Bala group, or Upper Cambrian of Sedgwick, consists there of

Bala Beds.

Upper Cambrian.[2]	Lower Bala = Llandeilo flags (Upper Llandeilo of the Geological Survey, the Arenig being the Lower). Middle Bala = the Caradoc Sandstone, Bala rocks, and Coniston limestone (Geological Survey). Upper Bala = the Caradoc Shales, Hirnant Limestone, and Lower Llandovery rock (Geological Survey).

The Upper Llandovery or May Hill Sandstone overlies these unconformably. Hence Sedgwick's Middle Bala and part of the Upper are equivalent to the true Caradoc of the Geological Survey, and as such we treat that group here; the Middle Bala of the Cambridge Catalogue will therefore embrace the whole of the 600 species known as Caradoc

[1] Catalogue of the Collection of Cambrian and Silurian Fossils contained in the Woodwardian Museum of the University of Cambridge, by T. W. Salter, with Preface by the Rev. A. Sedgwick, LL.D., F.R.S., &c.

[2] *Vide* Woodwardian Catalogue, Cambridge, pp. 25, 26, &c.

forms.[1] The Lower Bala includes certain dark earthy slates and bands of limestone occurring on the east flank of the Arenigs, Mynydd Tarw, and Craig-y-glyn above Llanarmon in the Berwyns, the black slates on the flanks of Snowdon, also the arenaceous deposits on the west side of Bala Lake below the Bala Limestone, and that limestone also.

The Middle Bala group of the Woodwardian Catalogue embraces the Bala Limestone and its associated sandstones and slates in North and South Wales. In Shropshire it is the Caradoc Sandstone with its Horderley Limestone. The Coniston and Kildare limestones, and the Craig Head and Peebles limestones, are all of this age.[2] This middle group (the richest in organic remains) may represent the whole of the Caradoc Sandstone proper as developed in Shropshire.

Coniston Limestone.

This series succeeds and conformably overlies the Borrowdale series of the Lake area, and consists of bands of limestone separated by intercalated hard grey or bluish-cleaved shales. In the Sedbergh area the limestone passes upwards into the "*Trinucleus* and *Strophomena* shales." West of Coniston Lake, and in the neighbourhood of Millom, a considerable mass of shales overlies the highest bed of true limestone, but palæontologically there appears no difference between them and the limestones.

Lithologically, the term "Coniston Limestones" is somewhat misleading, as it is never wholly calcareous in its composition. In its most typical state, as it ranges between Long Sleddale and Broughton Mills in Furness, the Coniston limestone consists of hard grey or bluish-grey cleaved calcareous shales, containing numerous nodules or thin bands of limestone. The fossils of the Coniston Limestone are numerous, but as a rule not well preserved. The shales hold the chief fauna, but are much distorted by cleavage.

Fauna of the Coniston Limestone.—The following is a list of the more important species which occur, and may be considered characteristic:—

ACTINOZOA.—*Heliolites interstinctus, Halysites catenularia, Petraia æquisulcata, Stenopora fibrosa, Nebulipora lens, Chætetes* sp.

CRUSTACEA.—*Sphærexochus mirus, Cheirurus juvenis, C. bimucronatus, C. gelasinosus, C. cancrurus, C. octolobatus, Lichas laxatus, L. hibernicus, Illænus Davisii, I. Bowmanii, I. Rosenbergi, Calymene Blumenbachii, Agnostus* sp., *Phacops* (*Chasmops*) *macrourus* = (*Odontochile obtusicaudata*), *P. apiculatus, Ampyx Sarsii, Remopleurides. Proëtus* sp., *Bronteus* sp., *Beyrichia impendens, Primitia protenta, Cythere phaseolus.*

POLYZOA.—*Fenestella assimilis, Ptilodictya costellata.*

BRACHIOPODA.—*Lingula brevis, Strophomena corrugatella, S. rhombordalis, S. deltoidea, S. expansa, S. tenuistriata, Orthis biforata, O. calligramma, O. flabellulum, O. actoniæ, O. vespertilio, O. porcata, O. elegantula, Discina corrugata, Triplesia? monilifera, Atrypa imbricata, Leptæna tenuicincta.*

PTEROPODA.—*Theca triangularis, Conularia elongata.*

CEPHALOPODA.—*Orthoceras vagans.*

[1] Consult the table of equivalents of the strata underlying the May Hill Sandstone, Woodwardian Catalogue, p 25.

[2] *Vide* Woodwardian Catalogue, pp. 26–39.

No doubt can be entertained as to the precise age of the Coniston limestone, but whether it is on the horizon of the Bala limestone (Middle Bala) of North Wales is uncertain. The beds of Portraine, County Dublin, and the rocks and fossils of the Chair of Kildare, are certainly of Bala age, and our Lake fauna is precisely that of these localities. The Brachiopoda show this conclusively, as do also the Crustacea (*Trilobita*) through the following species :—*Sphærexochus mirus, Cheirurus juvenis, C. cancrurus, C. gelasinosus, C. octolobatus, Lichas laxatus, L. hibernicus, Illænus Bowmanni, I. Davisii, Phacops macrourus*, and *P. apiculatus*. These and the Brachiopoda constitute a characteristic assemblage of Caradoc or Bala types.

Conditions of Deposition.—The conditions under which the Coniston limestone was deposited seem to show that the volcanic activity which produced the vast mass of ash, breccias, and lavas constituting the Borrowdale series had not entirely died out during the formation of the Coniston limestone and Dufton shales, but continued to operate intermittently, or at intervals. "The Lake District could not have been entirely submerged at the time when the Coniston series began to be laid down. It would appear that a portion of the volcanic region must have remained above the level of the sea, the vents occasionally giving exit to showers of ashes, and even currents of lava. This again tends to show that there was no break in continuity between the close of the Borrowdale series of deposits and the commencement of the Caradoc series, but that the two groups of rocks are intimately connected and overlap each other in time."

This hypothesis receives support from the following views :—

1. Through the intercalation, at the close of the Borrowdale series, of a band of fossiliferous shales containing Bala species, which shows local volcanic energy still in force when the sea was tenanted with Bala Brachiopoda and Crustacea (Trilobita). The shales are separated from the Coniston *limestone proper* by a mass of lava, but palæontologically they form part of the Coniston series.
2. The presence of beds of ashes (containing fossils) high up in the Dufton shales at Swindale, near Knock, shows also that the volcanic eruptions of the preceding period had not entirely ceased when the Dufton shales were in course of deposition. These shales belong palæontologically to the Lower Coniston group, and were a local development of the base of the Coniston limestone.
3. The presence of interbedded felstones in the Coniston limestone in the Sedbergh district (as shown by Professor Hughes) conclusively proves the occurrence of volcanic eruptions contemporaneous with the deposition of the limestone. It has been suggested that "the Coniston limestone was deposited round the shores of the volcanic nucleus of the Lake District, much after the fashion that a modern limestone might have been in process of formation for thousands of years off the coasts of Sicily. In such a case, beds of limestone would wrap round sheets of lava, so as to be apparently transgressive thereon, or might be interstratified with strata of tuff, or ash, or of volcanic rocks (lava, &c.) Any seeming discordance between the calcareous series and the volcanic products would be due not to absolute unconformity, indicating *lapse of time*, but simply to the difference in the method by which the two groups were formed. In spite of apparent discordance, both groups would belong to the same period, and, in part, they would be actually contemporaneous" (*H. A. Nicholson*). If these in-

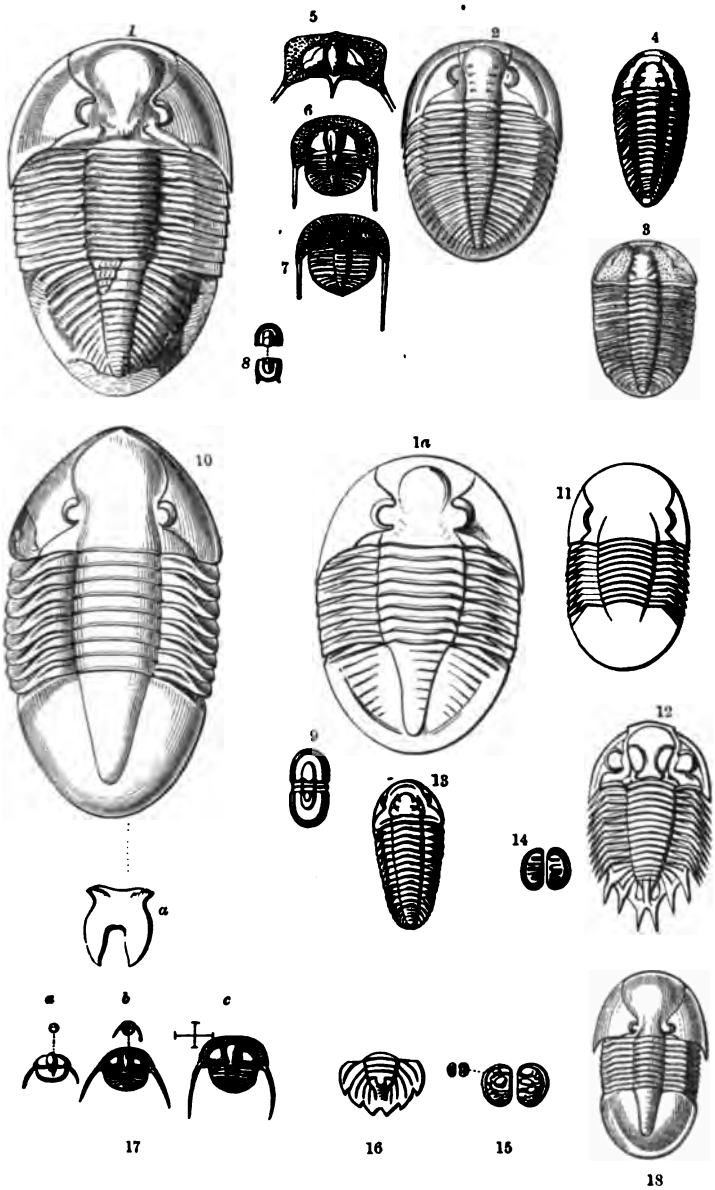
PLATE III.

LOWER SILURIAN FOSSILS.

1. *Asaphus tyrannus* (Murch.) Llandeilo rocks.
1a. *Do.* do. Do.
2. *Ogygia Buchii* (Brong.) Llandeilo flags.
3. *Calymene duplicata* (Murch.) Llandeilo and Caradoc rocks.
4. *Calymene brevicapitata* (Portlock). Ranges from the Llandeilo flags to Wenlock shale.
5. *Trinucleus concentricus* (Eaton). Caradoc and Llandovery rocks.
6. *Trinucleus Lloydii* (Murch.) Llandeilo and Caradoc.
7. *Trinucleus fimbriatus.* Llandeilo and Caradoc.
8. *Agnostus M'Coyi* (Salt.) Llandeilo beds.
9. *Agnostus trinodus* (Salt.) Caradoc.
10. *Asaphus Powisii* and *labrum*(*a*) (Murch.) Llandeilo and Caradoc.
11. *Illænus Davisii* (Salt.) Caradoc and Bala.
12. *Lichas laxatus* (M'Coy). Caradoc and Llandovery. Ireland.
13. *Calymene*, allied to *brevicapitata.* Caradoc.
14. *Beyrichia complicata* (Salt.) Llandeilo and Caradoc.
15. *Beyrichia tuberculata* or *Wilckensiana.* Caradoc or Bala.
16. *Pygidium* of *Lichas Barrandii?*
17. *Trinucleus concentricus* (Eaton). In three stages of development—(Barrande).
18. *Stygina latifrons* (Portl.) Caradoc. Ireland. (After Murchison, "*Siluria.*")

PLATE III.

LOWER SILURIAN FOSSILS.



Mudstone Fossils.—The following are the known species in the Graptolitic mudstones :—

ACTINOZOA.—*Favosites* sp.
BRACHIOPODA.—*Strophomena expansa, Orthis vespertilio, O. flabellulum,* and *O. elegantula.*
CRUSTACEA.—*Agnostus trinodus, Phacops apiculatus, Cheirurus bimucronatus, Harpes Flanagani, Calymene senaria, Trinucleus fimbriatus,* and *Discinocaris.*
CEPHALOPODA.—*Endoceras proteiforme* and *Orthoceras angulatum* are the only species of this class occurring in the mudstones.

Foreign Representatives of the Mudstones.—These beds constitute a geological horizon of much importance; they are recognised in Ireland, existing under similar conditions, and also occur in Sweden, Carinthia, and Bohemia. Dr. Linnarsson has shown that the "Upper Graptolitic Schists" of Sweden are the equivalents in that country of the Graptolitic mudstones of the Lake area.

In Scania they are overlain by undoubted Upper Silurian beds. In Carinthia, Dr. Guido Stache finds beds corresponding precisely with our Graptolitic mudstones,[1] their parallelism being complete. In Bohemia our mudstone beds are also represented in the "colonies" of Barrande's Etage D, and in the *lower* portion of Etage E. These beds are referred by M. Barrande to the base of the Upper Silurian. It is admitted by Barrande that "the succession of Silurian life in the Bohemian area was *later, stage by stage,* than in Northern European and British areas."

The Knock Beds.—The Graptolitic mudstones are succeeded by a series of strata composed of pale-green, fine-grained slates, ashy in appearance; red and purple slates also occur in bands of the same texture. These beds are well developed in Swindale Beck, near Knock. The general strike and dip of this series conform with those of the underlying "mudstones." Cleavage has distorted the fossils; and only two species of Graptolites are known at Knock, viz., *Monograptus priodon* and *M. Broughtonensis.* These "*Knock beds*" are surrounded by the Coniston flags (*Broughton Moor flags*), a series of strata corresponding to the "*Denbighshire flags*" of North Wales, of Upper Silurian age. They rest upon the "Graptolitic mudstones." It is therefore clear that the Knock beds either form the basement series of the Upper Silurian, or the summit series of the Lower Silurian, or a group of passage-beds between these two formations.

There is a strong lithological resemblance between the "Knock beds" and the "Tarannon shale or slates" of Wales.

We may, therefore, regard the Knock beds as the base of the Upper Silurian series of the Lake District, in which case the Graptolitic mudstone will constitute the highest portion of the Lower Silurians of the same area.[2]

Sedgwick's "Upper Bala" comprehends the Aber-Hirnant beds

[1] "Die Graptolithen-schiefer am Osternig-Berge in Kärnten."
[2] Two important members of the Silurian series appear to be wanting in the Lake country, viz., the Llandovery rocks and the Wenlock group.

above the Bala Limestone (with peculiar fossils), the lower part of the Coniston Flags (that conformable to the limestone), and all beds above the Bala Limestone and beneath the May Hill Sandstone. Again, the "Upper Bala" includes all the beds, whether near Meifod or Welchpool or Llanwyddyn, which lie above the Bala Limestone and under the unconformable cover of the Denbighshire grits and flags. The following species characterise the Upper Bala group, including the Aber-Hirnant beds above the Bala Limestone:—*Nidulites favus*, *Petraia uniserialis*, *P. rugosa*, *Phacops obtusi-caudatus*, *Atrypa marginalis*, *Meristella subundata*, *Orthis biforata*, *O. fissicostata*, *O. Hirnantensis*, *O. sagittifera*, and *Leptæna sericea*. In ascending order the Upper Bala includes—

Upper Bala (Sedgwick).
1. The Hirnant Limestone and Slate = Coniston Flags, lower part only (Ashgill, Coldwell, &c.), above the Coniston Limestone.
2. Llandovery beds (Lower Llandovery of Murchison) = the Mathyrafal Limestone, near Meifod, of Sedgwick.

"It is the great fossiliferous group of Haverfordwest. The Dalquorhan and Mullock beds in Ayrshire, the fossiliferous rocks of Maume and Cong in Galway, belong in part to it."[1] The Ayrshire equivalents, as developed at Dalquorhan and Mullock, possess a conspicuous fauna, yielding *Heliolites subtilis*, *Cyphaspis megalops*, *Illænus Thomsoni*, *Lichas bulbiceps*, *Illænus Bowmannii*, *Meristella angustifrons*, and *Bellerophon dilatatus*. The Shropshire fauna is in all respects the same as that of North Wales, and characterised by certain species of Trilobita, Mollusca, &c., viz., *Acidaspis caractaci*, *Homalonorus bisulcatus*, *Phacops conopthalmus*, *Lichas laxatus*, *Orthis vespertilio*, *O. actoniæ*, *Leptæna transversalis*, *Modiolopsis orbicularis*, *Ctenodonta varicosa*, *Murchisonia simplex*, *Cyclonema crebristria*, *Conularia sowerbyii*, *Bellerophon bilobatus*, and *B. acutus*. The fossils of Snowdon and Bala are identical with those of Shropshire; and the sandstones and impure limestones of Montgomeryshire (with *Trinucleus caractaci*, *Strophomena expansa*, &c.) are identical with the shelly beds of Caer-Caradoc, which are nearly 4000 feet thick.

CHAPTER XI.

PALÆONTOLOGY OF THE CARADOC ROCKS.

Caradoc Fauna.

Numerical Value of the Caradoc Fauna.—The three classes in the Caradoc having the greatest number in common are the Hydrozoa

[1] *Loc. cit.*, pp. 26, 72.

(Rhabdophora), the Crustacea (Trilobita), and the Brachiopoda. The number of known species in the Llandeilo in each of the above classes is—

Hydrozoa	44
Crustacea	45
Brachiopoda	34

In the Caradoc fauna the same three classes number, including those common to or from the Llandeilo—

Hydrozoa	38
Crustacea	146
Brachiopoda	109

Numerically, the remaining ten classes have little value for comparison, although the Actinozoa, Echinodermata, Pelecypoda, and Gasteropoda are well illustrated. It is through the above three extensively developed groups, which are chiefly moderately deep-sea forms, that the two formations are united.

The fact of 77 species out of 175 passing from the Llandeilo to the Caradoc is highly suggestive, and is confirmatory of the views of Sedgwick in uniting the Llandeilo to the Lower Bala; and the distinctiveness of the great Middle Bala is confirmed by the fact that, out of 610 species in that formation, only 102 pass to the Lower Llandovery. Therefore, on palæontological data, we may regard the Llandeilo and Caradoc as being most closely allied. The 102 transgressive Caradoc species are distributed through the following classes :—

Number of Species that Survive or Pass from the Caradoc to the Lower Llandovery Rock.

Protozoa	1	out of	10	Pass to Lower Llandovery (102).
Hydrozoa	1	„	36	
Cœlenterata	20	„	40	
Annelida	2	„	15	
Echinodermata	2	„	32	
Crustacea	16	„	146	
Bryozoa	4	„	21	
Brachiopoda	34	„	109	
Lamellibranchiata	3	„	76	
Gasteropoda	10	„	53	
Pteropoda	1	„	12	
Heteropoda	1	„	15	
Cephalopoda	7	„	47	
	102	„	612	

The Crustacea number 146 species, of which 106 are peculiar; 20 species pass up from the Llandeilo below, and 16 pass to the Lower Llandovery, thus leaving for the Caradoc and Bala beds the largest Crustacean fauna known in the Lower Palæozoic rocks. The Brachiopoda number 109 species, representing 16 genera; they are more numerous in the Caradoc than in any other of the Palæozoic rocks. Thirty-three of the 109 pass to the Lower Llandovery. As regards

geographical distribution, North Welsh forms greatly predominate, owing probably to the larger amount of research to which the rocks of the four counties of Caernarvon, Denbighshire, Montgomeryshire, and Merioneth have been subjected. Ireland also has yielded 60 species, and Scotland 40.

The littoral or shallow-sea condition of the Caradoc is further illustrated by the occurrence of a large number of bivalve or Pelecypod Mollusca. Seventy-six species are known; and of these only 3 species pass to the Lower Llandovery, viz., *Pterinæa retroflexa*, *Orthonota sulcata*, and *Mytilus mytilimeris;* so that 66 species belong exclusively to the Caradoc, and these are the *only species known in the whole of the succeeding Lower Llandovery rocks.*

The PELECYPODA of the Caradoc exceed in number those of any other known formation below the Carboniferous Limestone. Careful analysis shows that 76 species occur.

The Gasteropoda are represented by 14 genera and 53 species. Ten pass to the Lower Llandovery. *Cyclonema crebristria*, *Holopella cancellata*, *H. tenuicincta*, *Murchisonia cancellata*, *M. pulchra*, *Trochonema triporcatum*, and *Rhaphistoma lenticulare* also occur in the Lower and Upper Llandovery. Only 3 species pass to the Wenlock rocks. The Gasteropod fauna, therefore, is as significant as the Pelecypod, no fewer than 32 of the 53 species being confined to the Caradoc or Bala group. Sixteen of the 53 are peculiarly Irish forms, and 5 are Scotch, leaving 21 for distribution through the North and South Welsh and English beds. North Wales yields 26 species.

The PTEROPODA (4 genera and 12 species) are, with 4 exceptions, confined to the Caradoc. *Conularia Sowerbyi* passes to the Lower Llandovery, Wenlock, and Ludlow; *Ecculiomphalus scoticus* is Llandeilo, Caradoc, and Upper Llandovery. The Pteropoda, being strictly or essentially Pelagic, give us little clue as to bathymetric conditions at the time of deposition. Neither do the Cephalopoda, yet no single class is so pre-eminently Caradoc: of the 47 known species, only 1 (*Orthoceras arcuoliratum*) unites it with the Llandeilo group, and only 7 connect it with the Lower Llandovery above. The 7 species are *Lituites cornu arietis*, *Orthoceras ibex*, *O. vagans*, *O. annulatum*, *O. Barrandii*, *O. politum*, and *O. tenuistriatum*. The 3 species that directly unite the Caradoc and Lower Llandovery are *O. vagans*, *O. annulatum* and *O. Barrandii*. Ireland is represented by 24 of the 47 species, 18 of which do not leave the Caradoc horizon, and 17 are strictly confined to the Irish deposits.

Of the Scotch Caradoc Cephalopoda we only know of 6 restricted species, viz., *Orthoceras audax*, *O. arcuoliratum* (also Llandeilo), *O. vaginatum*, *O. politum*, *O. primævum*, and *O. tenuistriatum*.

Geographical Distribution of the Caradoc Species.

Distribution in Space of the Caradoc Fauna.—We have now to treat of the geographical distribution of the extensive series of species occurring in the Caradoc or Bala rocks, the large fauna (614 species)

being an additional reason for examining the subject, more especially with reference to the widely spread area occupied by the Lower and Middle Bala groups. It would be impossible to name a tithe of the localities whence our knowledge of their distribution has been derived; but the chief districts in North Wales number between 30 and 40, and in South Wales about 10. The Shropshire and Westmoreland localities, though less numerous, are prolific in species.

The following 10 areas, including about 50 localities in the British Islands, have yielded the 614 species known:—

North Wales.	Caernarvonshire	105	species, distributed in	10	chief	localities.
	Denbighshire	131	" "	6	"	"
	Montgomeryshire	138	" "	5	"	"
	Merionethshire	162	" "	10	"	"
South Wales.	Pembrokeshire	93	" "	5	"	"
	Caermarthenshire	72	" "	5	"	"
England.	Shropshire	123				
	Westmoreland	123				
Scotland		302				
Ireland		306				
		1555				

Distribution in Time of the Caradoc Fauna.—The actual number of species (so far as at present known) occurring in North Wales is 270, in South Wales 134, in Shropshire 123, in Westmoreland 123, in Scotland 302, and in Ireland 306.

The intimate relation of the Caradoc to the succeeding Lower Llandovery rocks obliges us to show their specific affinity, for the purpose of ascertaining the palæontological value of the Lower Llandovery (the Upper Bala of Sedgwick). Analysis shows that, of the 614 Caradoc species, 103 pass to the *Lower* Llandovery; but 107 are also common to the Caradoc and *Upper* Llandovery, although we know of the stratigraphical break that occurs between the two formations. This relation is chiefly through the Actinozoa, Hydrozoa, and Brachiopoda, as we might expect from their bathymetrical habitats and ranges.

Of the 40 known species of corals, 22 range to the Llandovery rocks; and 37 species of Brachiopoda, out of the 109 known, pass to the Llandovery group, 33 of which are in the Lower Llandovery.

Of the 16 species of ANNELIDA, only 2 pass to the Lower and Upper Llandovery, *Tentaculites anglicus* and *Cornulites serpularius*: they survive and range to the Ludlow rocks.

The class ECHINODERMATA, represented by 32 species, is remarkable for the occurrence of 8 genera, illustrated by no less than 23 species of Cystidea. They essentially characterise the Caradoc or Bala rocks, and with one exception (*Echinosphærites arachnoidea*) all are peculiar. It is only in the Caradoc and Wenlock strata that the Cystidea appear as a well-developed and characteristic group of the Echinodermata; they attained their maximum development in the Caradoc Sea. The middle division of the Bala or Caradoc rocks is essentially characterised by *Echinosphærites*, *Sphæronites*, *Glypto-*

cystites, *Hemicosmites*, *Pleurocystites*, *Cyclocystites*, *Agelacrinites*, *Atelocystites*, &c. This family is replaced in the Carboniferous rocks by the Blastoidea (*Pentremites* and *Codaster*), and does not again appear.

Palæontology of the Caradoc Rocks.

Actinozoa.—In this class we know, through the fullest research, that 20 genera and 40 species occur. The following (13) genera, *Plasmopora*, *Syringophyllum*, *Halysites*, *Stylarœa*, *Omphyma*, *Thecostegites*, *Alveolites*, *Aulacophyllum*, *Calostylis*, *Cyathophyllum*, *Fistulipora*, *Tredadium*, and *Prosopora*, have as yet yielded only one species each.

The coral fauna of the Caradoc makes its appearance at once *underived*, the older Llandeilo possessing only 3 species of Actinozoa, *Halysites catenularius*, *Favosites fibrosus*, and *Monticulipora frondosa*; whereas, next to the Wenlock, the Caradoc possesses the largest Cœlenterate fauna of the Lower Palæozoic rocks, numbering 20 genera. In no other localities, either in Europe or America, does this class appear with so large a generic grouping. Twenty of the 40 species pass to the Lower Llandovery.

Crustacea.—The Crustacea pre-eminently characterise the Caradoc and Bala rocks, and constitute the largest group in the whole of the Palæozoic series; 37 genera and 146 species have been collected in the three countries, England, Ireland, and Scotland.

North Wales.	Caernarvonshire	has yielded	11	genera and 17	species.
	Denbighshire	„	17	„ 33	„
	Montgomeryshire	„	13	„ 29	„
	Merionethshire	„	16	„ 36	„
South Wales.	Pembrokeshire	„	16	„ 24	„
	Caermarthenshire	„	13	„ 20	„
England.	Shropshire	„	15	„ 31	„
	Westmoreland	„	18	„ 38	„
Scotland	. . . . .	„	31	„ 78	„
Ireland	. . . . .	„	31	„ 90	„

The most important genera (or those of chief stratigraphical value, and in which the species are numerous) are *Acidaspis* (8 species), *Ampyx* (6), *Agnostus* (5), *Asaphus* (6), *Calymene* (8), *Cheirurus* (6), *Homalonatus* (4), *Illœnus* (13), *Lichas* (6), *Phacops* (13), and *Remopleurides* (8). Those *essentially* characterising the Caradoc are *Harpes*, *Salteria*, *Remopleurides*, *Cyclopyge*, *Dionide*, *Tiresias*, and *Cyphoniscus*, most of which are only represented by one or two forms. Scotland and Ireland possess the richest assemblage of species, 26 genera and 63 species occurring in the former, and 23 genera and 77 species in the latter area. Only 15 of the 123 species of Trilobita pass to the Lower Llandovery; they are *Acidaspis Brightii*, *Calymene Blumenbachii*, *C. brevicapitata*, *C. caractaci*, *C. Allportiana*, *Cheirurus bimucronatus*, *C. clavifrons*, *Encrinurus punctatus*, *Cyphaspis megalops*, *Cybele verrucosa*, *Illœnus Rosenbergii*, *I. Bowmanni*, *I. Thomsoni*,

Lichas laxatus, and *Phacops Brongniarti*. The long-ranged species are chiefly those illustrating the largest or most extensive genera, such as *Calymene Blumenbachii*, *C. Allportiana*, *Cheirurus bimucronatus*, *Encrinurus punctatus*, *Cyphaspis megalops*, and *Phacops caudatus*, all of which species appear in the Ludlow and then cease to exist, the Devonian rocks having none in common; yet *Bronteus* and *Harpes* are repeated or recurrent genera from the Caradoc in the Middle Devonian, both in Britain and on the Continent. We must remember, however, that the marine Devonian nowhere visibly overlies the Silurian rocks in Great Britain, and the Old Red Sandstone contains no true marine form anywhere.

The order Ostracoda, illustrated by *Beyrichia*, *Leperditia*, *Cythere*, *Primitia*, and *Entomis*, needs little more than notice here, although it has received the closest scrutiny zoologically, palæontologically, and stratigraphically.

Brachiopoda.—Next to the Crustacea in force and classificatory value must be placed this group of Mollusca or Molluscoida. Individually or specifically, no class surpasses the Brachiopoda, many genera being, however, far more richly represented than others. In the Caradoc rocks this is notably the case. The genus *Orthis* is represented in Britain alone by no less than 110 species, and culminates in the Caradoc with 41.

The following table shows the specific and stratigraphical value of four important genera from the Cambrian to the Upper Silurian:—

TABLE IX.

	Longmynd.	Menevian.	Lingula Flags.	Tremadoc.	Arenig.	Llandeilo.	Caradoc.	Lower Llandovery.	Upper Llandovery.	Wenlock.	Ludlow.
Orthis . . .	...	1	1	4	10	13	41	20	10	16	7
Leptæna . . .	...	...	...	...	...	4	8	4	4	4	1
Strophomena . .	...	...	...	...	...	2	19	11	11	16	7
Rhynchonella . .	...	...	...	...	...	1	8	7	9	10	5
	...	1	1	4	10	20	76	42	34	46	20

Pelecypoda.—The species of Bivalvia in the Caradoc and Bala rocks are more numerous than in any other Lower Palæozoic group known, consisting of 76 species; while the Lower Llandovery has only 3, the Upper Llandovery 29, the Wenlock 45, and the Ludlow 71. These numbers help us to see, by comparison, the zoological value of the class Pelecypoda in the several strata, and the reasons for its absence or presence.

Ctenodonta, *Orthonota*, *Modiolopsis*, *Pterinæa*, *Ambonychia*, and *Palæarca* are the most prolific genera. The Caradoc Bivalvia excel in number those of all strata beneath the Carboniferous. The following

table, through the six Caradoc genera above named, shows this:—

TABLE X.

	Longmynd.	Menevian.	Lingula Flags.	Tremadoc.	Arenig.	Llandeilo.	Caradoc.	Lower Llandovery.	Upper Llandovery.	Wenlock.	Ludlow.
Ctenodonta . .	...	...	...	2	...	1	17	...	6	3	4
Orthonota . .	...	...	...	...	...	...	5	1	6	3	16
Modiolopsis . .	...	...	...	4	1	2	16	...	3	6	5
Pterinæa . . .	...	...	...	...	...	...	6	1	6	11	12
Ambonychia . .	...	...	...	...	...	...	8	...	...	2	1
Palæarca . . .	...	...	...	...	2	1	5	...	...	...	...
	...	...	...	6	3	4	57	2	21	25	38

Gasteropoda.—Like the three preceding classes, the group Gasteropoda is largely represented in the Caradoc strata, 14 genera and 53 species having been determined. None have yet occurred in Pembrokeshire, and only 3 in Caermarthenshire, viz., *Holopella cancellata*, *Patella saturni*, and *Cyclonema crebristria*.

Pteropoda.—Ten species of this class are known in the Caradoc; this is the largest Pteropod fauna in the Palæozoic rocks; they occur in nearly equal numbers through the ten areas, Ireland yielding nearly three times as many as Shropshire and Merioneth. No species is known in Pembrokeshire.

Heteropoda.—This order is represented in the Caradoc or Bala rocks by 10 species of *Bellerophon*, 2 of *Ecculiomphalus*, and 3 of *Maclurea*. In the British area the two last-named genera are restricted in their geographical range to Ireland and Scotland, and stratigraphically to the Arenig or Llandeilo and Caradoc. *Maclurea* occurs only in Scotland; *M. Logani*, *M. Peachii*, *M. macromphala*, and *M. magna*, are believed to be of Llandeilo age. The Durness species *M. Logani* and *M. Peachii*, with associated forms, may be Arenig. *M. M'Coyi*, *M. macromphala*, and *M. magna* are admitted to be with us of Caradoc age, and certainly occur low down in the series. Clonmel, Stinchar river, and Bugon, &c., in Ayrshire, and the Durness Limestones yield *M. Peachii* and *M. Logani* abundantly.

Piloceras invaginatum and *Orthoceras mendax* occur in the same beds. *Maclurea* abounds in the Chazy Limestone of the United States and Canada—beds probably to be correlated with our Lowest Llandeilo or Arenig.

The genus Bellerophon is illustrated by 10 species—*B. bilobatus* and *B. nodosus* occurring in all localities.

Cephalopoda.—No less than 47 species have been determined from the Caradoc series; their maximum development is in Ireland, where 6 genera and 24 species occur: none are known in Shropshire.

Westmoreland and Scotland yield 12 each. The Irish genera are *Cyrtoceras, Koleoceras, Lituites, Poterioceras, Trocholites,* and *Orthoceras.* Amongst Cephalopoda the Caradoc fauna is generally and specifically by far the largest in the Palæozoic rocks. Only one species (*Orthoceras arcuoliratum*) is common to the Caradoc and Llandeilo; but 15 species range upwards, 7 to the Lower Llandovery, 9 to the Upper Llandovery, 4 to the Woolhope, 9 to the Wenlock, and 3 to the Ludlow beds. The Middle Bala of Sedgwick of the Cambridge Catalogue includes the fine assemblage of fossils belonging to the Bala limestone, sandstones, and slates of North Wales, the Caradoc sandstones and the Horderly limestones of Shropshire, or the true Caradoc. It includes also the fossils of the Coniston Limestone, the Kildare, Craig Head, and Peebles Limestones. The Hirnant Limestone is not included in Sedgwick's Middle Bala, but constitutes the base of his Upper Bala group.

CHAPTER XII.

THE LLANDOVERY SERIES—LOWER LLANDOVERY ROCKS.

History.—The Llandovery Rocks were so styled by Sir Roderick Murchison from the town of the same name in South Wales, where the groups are well developed, and where also their stratigraphical relations to the underlying and older beds are clearly seen. They are divided into two series—*Upper and Lower*—the Lower group forming the close of the Lower Silurian series of Murchison, or Cambrian of Sedgwick, and the Upper or May Hill Sandstone forming the base of the Upper Silurian series. Whatever may be the value of the term "Llandovery," it represents an extensively developed deposit, the upper group of which has significance as affording a base line for the Upper Silurian rocks of Murchison.

The series occupies a vast area in Europe and America. In Sweden it constitutes a part of Angelin's *Region E;* while in Norway, the Lower Malmö, and in Russia, the Esthland and Livland Pentamerus groups correspond to our May Hill series. Barrande refers our beds to his *Étage E,* and these are probably the equivalents of the Medina, Clinton, and Niagara shales and limestones of North America.

Unconformity between Lower and Upper Llandovery.—Although the Lower and Upper Llandovery are unconformable to each other stratigraphically, still there exists a considerable community of species between them, uniting the two divisions; for out of the 68 genera and 204 species illustrating 14 zoological classes in the Lower Llandovery, 45 genera and 104 species pass up and palæontologically unite the two series.

Llandovery Fauna.—The known fauna of the Upper Llandovery

or May Hill series in Britain comprises 91 genera and 261 species—nearly 60 species more than has been yielded by the Lower division. Again, affinity with, and direct transmission to, the Wenlock series is marked by the passage to that formation of 59 genera and 126 species, so that the special fauna confined to the Upper Llandovery or May Hill series is a small one. The facies of the Lower Llandovery (as shown by the *Actinozoa*, *Crustacea*, *Brachiopoda*, and *Gasteropoda*) is largely Caradoc; not so much through the number of species common to both, as through the prevalence of certain forms of life which survived and lived on during the shallowing of the Caradoc Sea and reduction of its area—a process which contributed much to influence the life, habits, and distribution of the Lower Llandovery species at the close of the Caradoc period. Fifty genera and 103 species are common to the Caradoc and Lower Llandovery, while 49 genera and 107 species passed to the Upper or May Hill group, and this, as in the Lower Llandovery, through the 4 groups named. It is important to show in a tabular form the value of these 4 classes, which proportionately express the same as the whole 13.

TABLE XI.

	Caradoc.		Pass to			
			Lower Llandovery.		Upper Llandovery	
	Genera.	Species.	Genera.	Species.	Genera.	Species.
Actinozoa . .	20	40	9	20	6	17
Crustacea . .	37	146	10	16	11	17
Brachiopoda . .	15	109	8	33	8	27
Gasteropoda . .	14	53	6	10	8	10
	86	348	33	79	33	71

The presence and preponderance of certain species of the genus *Pentamerus* and *Stricklandinia* determine the Upper from the Lower Llandovery, and at once distinguish them from the Caradoc, in the rocks of which neither genus occurs.

The petrological structure of the rocks of both series, composed, as they are, of argillaceous sandstones and shales, hard coarse grits, and quartzose pebbly conglomerates, with occasional limestones, shows them to have been deposited in moderately shallow water, and over a sea-bottom decreasing in depth or slowly rising. Some authors would unite the Lower and Upper Llandovery rocks, and thus constitute them a *Middle Silurian group;* but on palæontological grounds this cannot be admitted, and the unconformity also of the Upper group upon the Lower represents a lapse of time of great duration. The number of species in the united fauna of the two Llandoverys is 465—230 of which (104 in the Lower, and 126 in the Upper) have no stratigraphical value, being species that are common to the Caradoc below and pass to the Wenlock above.

Lower Llandovery Rocks.

Lower Llandovery rocks
(*Upper Caradoc*).
Étage D. 5, *Barrande, Bohemia.*
Regio D. E. Harparum (*Angelin*), *Schistes de Westrogothie et Calcaire à Pentamerus* (*Scandinavia*).
Ontario Division. { *Medina Sandstone*, *Oneida Conglomerate*, } North America.

Distribution.—The Lower Llandovery group is known in North and South Wales, Scotland, and Ireland, and through the *Hydrozoa* (*Rhabdophora*) is believed to occur in Westmoreland, but we are acquainted with no other representative group in that county.

Value of the Llandovery Fauna.—South Wales and Scotland possess the largest fauna, the former yielding 52 genera and 120 species, and the latter 45 genera and 130 species. It is only through the Brachiopoda that North Wales may be said to be represented, for out of the entire fauna known in this area—22 genera and 43 species—8 genera and 22 species belong to that class. Of the 13 classes only the following 5 are represented, viz., Protozoa, Actinozoa, Crustacea, Polyzoa, and Gasteropoda—in all, only 14 genera and 22 species.

The total known fauna of the Lower Llandovery comprises 68 genera and 204 species. So close is the affinity and intimate faunal connection between the Lower and Upper Llandovery rocks, that, notwithstanding the unconformity of the Upper to the Lower, no less than 46 genera and 104 species are common to the two horizons; and nearly an equal number, or 50 genera and 105 species, pass up from the Caradoc into the Lower Llandovery rocks. The intimate connection with the Upper Llandovery is chiefly through the Actinozoa (20 species), Brachiopoda (38), Crustacea (10), and Gasteropoda (8). On palæontological grounds we may question the value of the Llandovery formation when so few species really belong specially to it. But for the abundance of certain *Pentameri* and their first appearance in time, we should scarcely recognise the fauna of the Llandovery rocks as being distinctive. These researches reveal the fact that this upper member of the Bala group has little claim to separation from it; for, as before stated, $\frac{50}{105}$ unite it with the Caradoc and Bala beneath, and $\frac{45}{104}$ with the Upper Llandovery above. The life-history of the latter, again, shows nearly one-half of its genera and species to be the same; out of 91 genera and 260 Upper Llandovery species, 45 genera and 104 species occur in the Lower group also, so that only 16 genera and 101 species are really distinctive Lower Llandovery species.

Numerically the geographical distribution is as follows:—

North Wales	.	22	genera	and	43	species,	illustrating	only 6 classes.
South Wales	.	52	„		120	„	„	all 13 „
Scotland	.	45	„		130	„	„	„ 12 „
Ireland	.	42	„		95	„	„	„ 10 „
Westmoreland		6	„		25[1]	„	„	only 1 class

The following table exhibits the number of species in the ten

[1] This through the Rhabdophora only.

groups that pass on to the Upper Llandovery, omitting the Protozoa, Echinodermata, and Pteropoda (6 genera and 6 species), none of which pass higher. The *entire* fauna comprises 68 genera and 204 species.

Lower Llandovery.	Class Hydrozoa	7	genera and	50	species, of these	3	genera and	15	species pass to	Upper Llandovery.
	,, Actinozoa	12	,,	26	,, ,,	9	,,	20	,, ,,	
	,, Annelida	2	,,	3	,, ,,	2	,,	2	,, ,,	
	,, Crustacea	13	,,	25	,, ,,	8	,,	10	,, ,,	
	,, Polyzoa	2	,,	5	,, ,,	2	,,	3	,, ,,	
	,, Brachiopoda	10	,,	59	,, ,,	10	,,	38	,, ,,	
	,, Pelecypoda	3	,,	3	,, ,,	2	,,	2	,, ,,	
	,, Gasteropoda	9	,,	13	,, ,,	6	,,	8	,, ,,	
	,, Heteropoda	1	,,	6	,, ,,	2	,,	2	,, ,,	
	,, Cephalopoda	3	,,	8	,, ,,	1	,,	4	,, ,,	
		62		198		45		104		

Thus, out of the 62 genera and 198 species in the Lower Llandovery,[1] no less than 45 genera and 104 species pass up to the overlying and unconformable Upper series. So far as regards species, the fauna is nearly the same; in the Brachiopoda no genus appears to have become extinct.

Passage Beds.—The two groups *May Hill Sandstone or Upper Llandovery* and the *Lower Llandovery* must be considered as constituting beds of passage between the Lower and Upper Silurian. It has been proposed, and with some reason, to assign to them the rank of a Middle Silurian group. We are not, however, prepared to adopt at present so complete a change in the received classification, but there is much to be said in its favour, there being little doubt that the two divisions of Lower and Upper Llandovery ought never to have been adopted unless a Middle Silurian group had also been accepted. In England we have drawn the line between Upper and Lower Silurian by classing the Upper Llandovery or May Hill beds with the Upper Silurian or Upper division, and the Lower Llandovery with the Lower Silurian or Upper Cambrian, and this mainly upon the evidential value of certain species of Pentameri. The species *P. oblongus* characterises the Upper, and *Pentamerus* (*Stricklandinia*) *lens* the Lower Llandovery; hence the term *Pentamerus* beds has been assigned to them, from the presence and abundance of these special forms.

Fauna.—It is equally important to compare the Caradoc fauna with that of the Lower Llandovery, since it will be found that, as stated, no less than 103 Caradoc species are common to the the Lower Llandovery, which, as we have seen, possesses in all 204 species. Of the 40 species of Caradoc corals (Actinozoa), 20 pass to Lower Llandovery; of the 146 species of Crustacea (Trilobita), 16 pass up to the Lower, and 17 to the Upper Llandovery; of the 109 species of Brachiopoda, 33 are common; of the 76 species of Pelecypoda in the Caradoc, only 3 species pass into the *Lower*, but 7 into the *Upper;* the Gasteropoda number 53 species, of which 10 pass to

[1] Omitting the Protozoa, Echinodermata, and Pteropoda, none passing up: less $\frac{1}{3}$.

the Lower Llandovery, and 16 to the Upper; while out of the 47 species of Cephalopoda, only 7 are common to the Lower, but 9 to the Upper Llandovery.

Faunal Relationship between Caradoc and Llandovery.—We thus see that the faunal relationship is greater between the Caradoc and *Upper* Llandovery than between it and the *Lower*, although the Caradoc as a whole yield 614 species, the Lower Llandovery 204, and the Upper 261. This, together with the unconformity noted, shows considerable bathymetrical disturbance and physical changes during the passage from the Lower to the Upper Silurian. The relationship, therefore, between the Caradoc and the two Llandovery is thus shown :—

The Caradoc fauna comprises	179 genera 614 species	Of these $\frac{80}{101}$ pass up to the Lower Llandovery, and $\frac{45}{101}$ to the Upper.
„ Lower Llandovery	68 genera 204 species	
„ Upper Llandovery	91 genera 261 species	

These results show how small is the difference between the two series in relation to the Caradoc or parent source. It is probable that this group has a much wider extension than is at present known, and that it occupies much of the large tract of undulating Silurian country through Cardiganshire and the adjacent counties. Professor Sedgwick's Plynlimmon group (in part) belongs to the Lower Llandovery. So far as we know, no patches of "Middle Silurian" (Llandovery) occur over the country west of the Snowdon chain, nor indeed for some distance east and south of it.

The chief localities in which these strata occur are Pen-y-craig and Mathyrafal on the banks of the Vyrnwy, south-west of Meifod, Guilsfield near Welshpool, Cefn near Buttington, and Meifod near Pembroke, Noeth Grug (Llandovery), Mandinam, Gorllwyn-fach (Llandovery), and Golen-goed.

Geographical Analysis.—Complete analysis shows that in North Wales there are only 22 genera and 43 species; in South Wales 52 genera and 149 species; only 17 being common to the two areas. Scotland has yielded 45 genera and 133 species, and Ireland 42 genera and 95 species. The four South Wales counties have yielded 149; they are thus distributed:—

TABLE XII.

Classes.	Cardiganshire.	Caermarthenshire.	Pembrokeshire.	Radnorshire.	Totals.
Protozoa	...	...	1	...	1
Hydrozoa	...	1	...	...	1
Actinozoa	1	10	8	4	23
Echinodermata	1	...	1	...	2
Annelida	...	1	1	1	3
Crustacea	1	2	6	2	11
Polyzoa	...	2	...	...	2
Brachiopoda	10	35	22	19	86
Pelecypoda	...	2	...	...	2
Gasteropoda	...	5	3	2	10
Heteropoda	...	2	1	2	5
Cephalopoda	...	2	...	1	3
	13	62	43	31	149

The predominating groups or classes are the Actinozoa and Brachiopoda.

The Moffat rocks (Birkhill division) stand alone as a northern group, and may be correlated with the Lower Llandovery rocks of Wales and Shropshire.[1] The well-defined and well-determined graptolite fauna of this group has been elaborately worked out by Professor Lapworth, who names nearly 60 species. Professor W. Keeping has also added to our knowledge of Central Wales (Cardiganshire), a region hitherto little known, and for the first time we have a general succession of the rocks of the Aberystwyth (metalliferous) and Plynlimmon Groups. The Aberystwyth grits contain numerous graptolites (*Monograpti*). The Metalliferous Slate group of the Devil's Bridge is rich in fossils (*Monograpti, Dictyonema, Calyptograpti, Rhizograpti,* and annelide tracks). The third or Plynlimmon group is unfossiliferous, but over 1000 feet thick: 42 species occur in the Aberystwyth grits, and the metalliferous slates.[2]

Every invertebrate class is represented in the Lower Llandovery, although irregularly distributed geographically. In North Wales 7 classes are not represented, in South Wales all the 13 occur; in Scotland 12, in Ireland 10 of the 13; in Westmoreland only 1, the Hydrozoa, and by 25 species. The following are the chief fossils in the Lower Llandovery fauna:—

PROTOZOA.—*Nidulites favus* and *Stromatopora striatella.*
ACTINOZOA.—*Favosites fibrosa* and *Halysites catenularia, Heliolites interstinctus, Petraia bina, P. subduplicata.*
CRUSTACEA.—*Proetus girvanensis, Illænus Bowmanni, Cheirurus bimucronatus, Trinucleus concentricus.*
POLYZOA.—*Ptilodictya costellata, Fenestella subantiqua.*

[1] Vide Geol. Mag., vol. iii., Decade ii. pp. 308–319, 350–360, 490–507, 544–552; also Q. J. G. S., vol. xxxiv. pp. 240–346.
[2] Ibid., vol. xxxvii. pp. 141–170.

BRACHIOPODA.—*Atrypa hemisphærica, Meristella crassa, Orthis Bouchardi, O. reversa, O. Mullockensis, Pentamerus* (*Stricklandinia*) *lens, P. undatus, Rhynchonella Llandoveryana, Spirifera plicatella,* and *Strophomena arenacea.*
PELECYPODA.—*Pterinæa retroflexa.*

Distribution of the Llandovery Fauna.—In our analysis of the Lower Llandovery species from the rocks of that age in North and South Wales, Scotland, and Ireland, we have brought together all that is known relative to the range and distribution of life through this Middle Silurian or Upper Bala group of Sedgwick—the group which stands between and connects the Lower Silurian of the Geological Survey with the well-defined succeeding Wenlock and Ludlow series. We have already stated how small a specifically characterised group the Lower Llandovery appears to be, for only 115 out of 204 species really belong to that division. The total number known for all Britain is 68 genera and 240 species; but 50 *genera and* 104 *of these species transgressed* or came from the Caradoc and Bala beds below, thus reducing the actual Llandovery fauna to 18 genera and 100 species.

No species of Echinodermata occurs in the Lower Llandovery of North Wales, Ireland, or Westmoreland. No Lower Llandovery annelid is known in North Wales. Neither do we know of any Pelecypod, Pteropod, Heteropod, or Cephalopod in the same area.

Hydrozoa.—The careful researches and generalisations of Linnarsson in Sweden, Lapworth, Nicholson, Carruthers, and Hopkinson in Britain, Hall in America, and Barrande in Bohemia, upon the history, morphology, and distribution of the Rhabdophora through the Lower Palæozoic rocks of Britain, Europe, and North America, have greatly added to our knowledge of their stratigraphical value and distribution both in time and space. Until the analysis and descriptions of the Rhabdophora by Professors Lapworth and Nicholson appeared, we had little clear knowledge of their zoological grouping or stratigraphical distribution and relations to other geographical areas, either in Britain, Europe, or America.[1]

We know of few or no Lower or Upper Llandovery Hydrozoa in Wales. The Coniston Mudstones (Westmoreland) yield 6 genera and 25 species; and these probably belong to the Lower Llandovery series. The value, however, of the Scotch deposits, and their Graptolithic fauna of 50 or more species, is very great. They clearly show us that the paucity of species in the Welsh rocks is due probably to geographical and other physical changes. South of Westmoreland this group had scarcely a representative after the deposition of the Caradoc, few or none having survived the close of the Upper Bala period. The conditions seem to have been highly favourable, however, for their development during the formation of the Arenig, Llandeilo, Caradoc, and Lower Llandovery rocks, as shown in the following table:—

[1] *Vide* Lapworth, A. Mag. Nat. Hist., ser. v., vols. iii. and iv., for complete analysis of the Rhabdophora of the Moffat series of Scotland.

PLATE IV.

LOWER AND UPPER SILURIAN FOSSILS.

Lower Silurian.

TRILOBITA.

1. *Phacops conophthalamus.* Caradoc sandstone.
2. *Cybele verrucosa.* Caradoc and Lower Llandovery.
3. *Cheirurus clavifrons.* Caradoc.
4. *Remopleurides dorso-spinifer.* Caradoc rocks.
5. *Harpes flanagani.* Caradoc rocks.
6. *Ampyx nudus.* Llandeilo and Caradoc.
7. *Acidaspis bispinosus.* Caradoc rocks.
8. *Cyphoniscus socialis.* Caradoc rocks.
9. *Lichas anglicus Beyr.* Dudley, &c.
10. *Calymene tuberculata* (Salt.) Kendal. Barrington.
11. *Trinucleus concentricus.* Llandeilo and Lower Llandovery.
12. *Œglina mirabilis.* Showy large reticulated eyes. Llandeilo and Caradoc.

BRACHIOPODA.

13. *Orthis alata.* Arenig rocks.
14. *Orthis striatula.* Arenig, Llandeilo, and Caradoc.
15. *Lingula attenuata.* Arenig, Llandeilo, and Caradoc.
16. *Lingula granulata.* Llandeilo and Caradoc.
17. *Lingula Ramsayi.* Llandeilo.
18. *Siphonotreta micula.* Llandeilo and Caradoc.
19. *Theca reversa.* (Pteropoda.)

Upper Silurian.

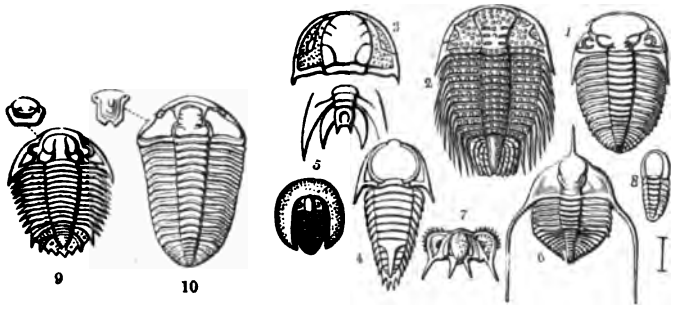
PELECYPODA.

20. *Avicula Danbyi.* Wenlock and Ludlow.
21. *Pterinæa asperula.* Wenlock.
22. *Pterinæa tenuistriata.* Wenlock and Ludlow.
23. *Pterinæa planulata.* Upper Llandovery to Wenlock.

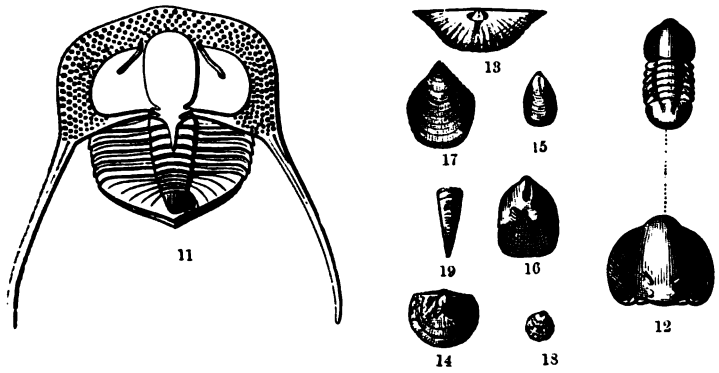
PLATE IV.

LOWER AND UPPER SILURIAN FOSSILS.

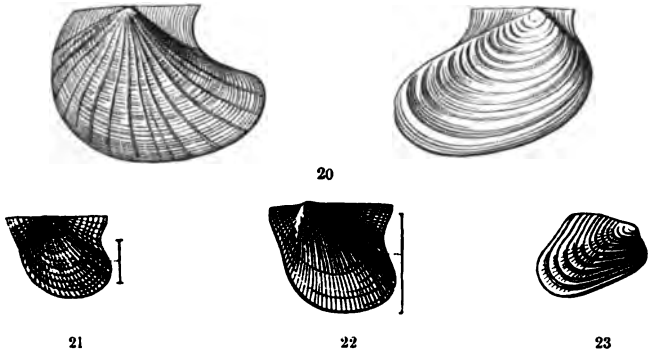
Lower Silurian—Trilobita.



Brachiopoda.



Upper Silurian Pelecypoda.



Rhynchonella tripartita, *Spirifera exporrecta*, *Strophomena arenacea*, *Stricklandinia lens*, *Pentamerus oblongus*, and *P. undatus*. The first appearance of *Pentamerus* and *Stricklandinia* is an important feature in the Lower Llandovery beds. Three species of *Pentamerus* (*P. oblongus*, *P. globosus*, and *P. undatus*) are Lower and Upper Llandovery forms; the 2 species of *Stricklandinia* (*S. lens* and *S. lirata*) also are common to both horizons.

Pelecypoda.—No species of this extensive group of Mollusca occurs either in North Wales or in Scotland; and we are only acquainted with 3 genera and 3 species in the Lower Llandovery, viz., *Pterinæa retroflexa*, *Mytilus mytilimeris*, and *Orthonota sulcata;* these 3 are South Wales forms, and the *Pterinæa* also occurs in the Irish Llandovery. This meagre representation of so large a class in these beds as compared with the Caradoc (16 genera and 76 species) clearly shows that, at the close of the Caradoc and Bala period, great changes took place with regard to the relations of land and sea. The Caradoc sea evidently shallowed and reduced its area, and this was accompanied by corresponding sedimentary changes which governed the life, habits, and distribution of the succeeding Llandovery fauna. This is borne out by the Brachiopoda and other groups, which then reached great perfection, but declined in the succeeding Llandovery.

Doubtless the strictly arenaceous nature of the deposits, and the somewhat shallow sea, constituted the main cause of this extremely small bivalve fauna. Two of the three species of Conchifera are Caradoc, and the same two passed to the Upper Llandovery, so that in reality only one species is to be regarded as Lower Llandovery, viz., *Pterinæa retroflexa*.

Gasteropoda.—Although this class includes a much greater number of species than the Pelcypoda, yet the value of the fauna for classificatory purposes is equally unsatisfactory, only *Murchisonia Pryceæ*, *M. sulcata*, *Platyschisma Williamsoni*, *Acroculia haliotis*, *Trochus Moorei*, and *T. multitorquatus* are truly Lower Llandovery.

Pteropoda.—*Conularia Sowerbyi* is the sole Pteropod known, and this species has only occurred in South Wales and Scotland; none are known in North Wales or Ireland.

Heteropoda.—*Bellerophon carinatus*, *B. bilobatus*, and *B. dilatatus?* are the chief Lower Llandovery species. The same 3 are Caradoc, and *B. carinatus* and *B. bilobatus* also occur in the Upper Llandovery of South Wales and Scotland.

These two nocturnal and pelagic groups, the Heteropoda and Pteropoda, from their habit, had a wide geographical distribution, and consequently a long range in time also.

Cephalopoda.—We have seen that the Lower Caradoc and Bala rocks have yielded no less than 8 genera and 47 species; the Lower Llandovery, the highest member of the Bala formation, has, on the contrary, only 3 genera and 8 species distributed through the 6 areas in which this formation is represented. The genera are *Lituites*, *Tretoceras*, and *Orthoceras*. The species in *Lituites* are *L. cornuarietis* and *L undosus;* the second (*Tretoceras*), *T. bisiphonatum;*

and *Orthoceras* contains 5 species, *O. annulatum*, *O. ibex*, *O. politum*, *O. tenuistriatum*, and *O. vagans?* Of these no species occurs in North Wales. South Wales, however, in the Llandovery area, has yielded 5 species, Scotland 2 (*Orthoceras politum* and *O. tenuistriatum*), and Ireland only 1 species (*Orthoceras ibex*).

The accompanying Table is constructed to show the geographical distribution and value of the Lower Llandovery fauna, with relation to the Upper Llandovery; and also to show the number of species common to the two (unconformable) series, forming the close of the Lower and commencement of the Upper Silurian.

TABLE XIII.—*Lower Llandovery.*

From Caradoc.	Classes.	Genera.	Species.	Geographical Distribution.					Pass to Upper Llandovery.
				North Wales.	South Wales.	Scotland.	Ireland.	Westmoreland.	
...	Plantæ . .	...	...	...	...	...	...	...	...
	Protozoa . .	3	3				...	...	...
	Hydrozoa . .	7	50	...					
	Actinozoa . .	12	26					...	
	Echinodermata .	2	2	...			...	...	...
	Annelida . .	2	3	...				...	
	Crustacea . .	13	25					...	
	Bryozoa . .	2	5					...	
	Brachiopoda .	10	59					...	
	Lamellibranchiata	3	3	...				...	
	Gasteropoda .	9	13					...	
	Pteropoda . .	1	1	...			...	...	...
	Heteropoda . .	1	6	...				...	
	Cephalopoda .	3	8	...				...	
		68	204						

CHAPTER XIII.

UPPER SILURIAN SERIES.

UPPER SILURIAN—(*Murchison*, *Phillips*, *Lyell*, and *Julea*.)
Silurian. (Sedgwick.)
Murchisonian. (d'Orbigny.)

Geographical Distribution.—The rocks of the Upper Silurian series are best seen in the typical Silurian area, *i.e.*, in South Wales, Shropshire, Herefordshire, and Worcestershire, &c., or much of the area occupied by the southern border counties of England and Wales. They occur also in the lake district of Westmoreland and Cumberland, and in several localities in Scotland and Ireland.

The Dingle group is seen in Ireland in four localities, viz., Anascaul, Smerwick, Ferriters Cove, and Croaghmarhin.

In the Killary district, again, they form five distinct groups, designated by Mr. G. H. Kinahan as the Culfin, Lough Corrib, the Mweelrea and Toormakedy, the Creggaunbaun and Louisburgh respectively.[1] The Upper Silurian rocks of Ireland are of great thickness, nearly 15,000 feet.

It is almost impossible to divide the Upper Silurian rocks of Scotland into the two English types of Wenlock and Ludlow. They appear to belong chiefly to the lower portion of the Upper Silurian, though the Old Red Sandstone of the counties of Edinburgh and Lanark graduates down into thick beds of brown, olive, and grey shales, grits, and sandstones, in which occur undoubted Ludlow fossils. In the brown shales and olive-coloured mudstones, similar to those of the Ludlow area, are found the characteristic fossils, 65 species of which are known in Scotland.

The series of strata in the British Islands classed as Upper Silurian occur under two different types, manifest on comparing those in the original Silurian area in Herefordshire, with rocks of the same age in North Wales and Westmoreland.

In the southern border counties, the strata are scarcely disturbed from their original horizontal position, and consist of unaltered shales, with here and there bands of limestone.

In North Wales, on the other hand, a different physical type is observable. These deposits may be traced into beds of hard shales and grits, and but for fossil evidence cannot be physically or lithologically separated from the Caradoc and Llandeilo group. Comparison of organic remains alone reveals their true age. In Westmoreland, Cumberland, and the northern border counties, they exhibit more or less exactly the North Wales type, which is again seen in the south-west of Ireland. The general "petrological characters and palæontological sub-divisions of the original Silurian district are chiefly confined to it, while over the rest of the British area, for thousands of square miles, the hard, sandy, and shaly type of North Wales prevails."

Unconformity between the Upper and Lower Silurian.—The Upper Silurian tract exposed in the West of England, and the East and South of Wales, shows unconformity between the Upper and Lower Silurian deposits. This takes place between the Lower and Upper Llandovery, the latter group in many areas covering the upturned edges of all the older underlying strata, from the Cambrian to the highest division of the Lower Silurian rocks. In one area, between the Longmynd and Wenlock Edge to the east, the base of the May Hill sandstone in the space of a few miles covers up the Caradoc and the Lower Cambrian rocks. It is manifest from this succession, that great disturbance and extensive denudation preceded the commencement of the deposition of the Upper Silurian rocks (May Hill sandstone). This physical break is to be traced throughout their entire distribution. It took place during the time

[1] "Geology of Ireland," G. H. Kinahan, F.G.S., M.R.I.A.

of submergence, as is proved by the occurrence of conglomerates and sandy strata on the slopes and summits of the hills, which are composed of the more ancient and overlying rocks.

Sub-divisions of the Upper Silurian Series.—The following are the typical sub-divisions of the Upper Silurian Rocks in Britain :—

Base of Old Red Sandstone.

Upper Silurian.	3. Ludlow Group.	Tilestones and Downton Sandstones, 1000 ft. Upper Ludlow Rock, 900 ft. Aymestry Limestone, 150 ft. Lower Ludlow Rock, 900 ft.	Kirkby Moor-flags.
	2. Wenlock Group.	Wenlock or Dudley Limestone, 150 ft. Wenlock Shale Sandstone and Flags, 50 ft. Woolhope or Bar Limestone and Shale. Tarannon Shale (pale slates, Stockdale slates), 600 ft.	Denbighshire Grits of N. Wales.
	1. Upper Llandovery or May Hill Group.	May Hill Sandstone, 900 ft. Lower Llandovery Rocks.	

This group is the equivalent of the "Clinton" series of North America, and the Upper Anticosti group of Canada. In the May Hill and Malvern areas, these rocks, about 1000 feet in thickness, are typically developed, and composed of grey and yellowish sandstones, with bands of impure limestone, rich in organic remains.[1]

The Upper Llandovery is represented by nearly all the classes of the Invertebrata (13); and the whole fauna numbers 91 genera and 261 species, distributed through 11 well-marked geographical areas. The following 6 classes are those most numerously represented—

	Genera.	Species.
Actinozoa	16	32
Crustacea	11	24
Brachiopoda	13	65
Pelecypoda	12	29
Gasteropoda	13	28
Cephalopoda	6	19
	71	197

Local Distribution.—On the west flanks of the Malvern Hills, at Woolhope, May Hill, and Tortworth, at many localities in Shropshire (Norbury, Cherbury, Church Stretton, &c.), and at Llandovery, Presteign, &c., in South Wales, the Upper Llandovery or May Hill beds are typically exposed.

Many names have been proposed for these variable beds, such as *Upper Caradoc*, *Pentamerus*-beds, *Wenlock Grit*, &c.; but, through their chief development at Llandovery and May Hill in Gloucestershire, the double name of the "Upper Llandovery," or "May Hill Sandstone," has been assigned to them. In North Wales the

[1] Q. J. G. S., vol. ix. p. 215. Professor Sedgwick was the first to point out the necessity for separating these beds from the Lower Silurian, and proposed the name of "May Hill Sandstone" for them.

Upper Llandovery rocks are absent; in South Wales they first appear in Marloes Bay, and here and there across Pembrokeshire. Near Llandeilo, in Caermarthenshire, they lie at the base of the Upper Silurian rocks, and are most variable in thickness. They transgress or lie indifferently and unconformably on Lower Llandovery, Caradoc, or Llandeilo beds. In Shropshire they are markedly unconformable to the Caradoc; both in Shropshire and at Builth the unconformity is visible. In the Longmynd area, under the condition of a calcareous conglomerate, they rest upon all the older rocks exposed. They rise from under the Wenlock Shale at Noeth Grug, strike to near Llandovery and Pen-y-lan; again they range uninterruptedly from Marloes Bay, in Pembrokeshire, where they are highly fossiliferous, through Caermarthenshire to Builth, and on to the Longmynd and the typical Silurian country of Shropshire. They everywhere rest unconformably upon the older rocks, sometimes lying on the denuded edges of the Lower Llandovery or on the Caradoc Sandstone; at Builth and the Longmynd on the contorted and denuded Arenig, Llandeilo, and Cambrian strata. The lower Lickey Hills in Worcestershire, Tortworth, and part of the Shelve country, and Presteign, all exhibit the Upper Llandovery sandstones. These Pentamerous beds are from 800 to 1000 feet thick.

Relation between Upper and Lower Llandovery Species.—The absolute unconformity of the Upper Llandovery beds to the strata below, coupled as it is with changes of species, is doubtless connected with a great lapse of unrepresented time. Looking at the intimate connection between the fauna of the Lower Llandovery and that of the Upper, we are, however, led to *suppose that it was not of sufficiently long duration to cause either the extinction or migration of the older fauna or the introduction of a new one.* Only four new genera seem to have appeared, and we have seen that the Lower Llandovery transmitted 45 genera and 104 species, out of its fauna of 68 genera and 204 species, to the Upper Llandovery. It is therefore evident that upheaval and denudation must have been of comparatively short duration, and little physical change could have taken place in the area occupied by the Lower Llandovery after upheaval; this the physical geography and palæontology of the two groups help to show.

Characteristic Fossils.—The preponderance of individuals in species of the genera *Pentamerus* and *Stricklandinia*, especially *P. oblongus*, *S. lens*, and *S. lirata*, which are the best known and most widely spread, is a marked feature in the Upper Llandovery rocks, and imparts to them a peculiar and distinct facies. These species are met with, though not so plentifully, in the Lower Llandovery. The Malvern and May Hill form is *S. lens*, and it occurs in profusion. Granting the high value of the unconformity as of paramount stratigraphical importance, yet the community of fossils and general facies of both horizons lead us to regard the species as belonging distinctively to neither; for certainly the Lower Llandovery was an expiring close to the Caradoc and Bala, through elevation of the Caradoc sea-bed, and the Upper to the Lower through continuity of certain species.

The introduction of new forms commenced at the base of the Upper Silurian.

Palæontology of the Upper Llandovery Beds.

Plantæ.—*Fucoides gracilis* is the only plant known, and this is probably only one of the many forms of Annelid, or molluscan tracks or burrows, which simulate the habit of some of the marine algæ.

Protozoa.—*Clathrodictyon vesiculosum* and *Cliona* (*Vioa*) *gracilis* constitute the only two species known. The former occurs in the Llandovery rocks of Scotland; the latter appears to be a dichotomizing, burrowing sponge, found in the shelly structure of *Pterinæa* (*P. demissa*) from the Upper Llandovery of the Malvern Hills. This is probably the oldest known *burrowing* sponge; its habit is quite that of the modern genus *Cliona*.

Hydrozoa.—The genera *Monograptus, Cyrtograptus, Diplograptus,* and *Retiolites,* alone seem to represent the Rhabdophora in the Upper Llandovery rocks; but so many species appear to be common to the Lower and Upper Llandovery, that it is with difficulty we are enabled to realise the distinctness of the two Graptolite faunas. The Irish, Scotch (Girvan, Gala, and Mulloch beds), and the Coniston flags and Mudstones have so many species in common with the Lower Llandovery that only through intimate and practical acquaintance with the two groups of species can they be separated. In the Valentian or Llandovery-Tarannon series of Lapworth, including the Birkhill series and its several zones, many species of *Monograptus, Diplograptus,* and *Cyrtograptus* appear to be common. Probably the Upper Llandovery rocks of Ireland yield 6 or 8 species; the Girvan and Gala group about 30; and the Mulloch and Coniston beds 25 species; but many also belong to the Lower Llandovery below.

Actinozoa.—Zoologically, this is an important group in the Upper Llandovery, from the number of genera occurring and the numerically few species, 11 of the 16 genera being only represented by 1 in each. These are *Alveolites, Cœnites* (probably one genus), *Halysites, Labechia, Omphyma, Plasmopora, Ptychophyllum, Lindströmia, Propora, Pinnacopora,* and *Streptelasma.* The remaining 5 genera, *Favosites, Heliolites, Palæocyclus, Petraia, Syringopora,* unitedly yield 16 species. Their distribution is equally significant, showing that the two chief compound genera, *Favosites* and *Heliolites,* are, with the exception of *Petraia,* the most widely dispersed geographically. *Petraia* occurs in all localities; and perhaps no single genus has so wide a range or such persistent representative forms.

Echinodermata.—In this group we have 5 genera and 5 species. The Pembrokeshire rocks have yielded *Actinocrinus pulcher?, Cyclocystoides Davisii, Palæchinus Phillipsiæ*—the last named being *the first known representative* of the Echinoidea in time. The Perischoechinidæ, to which family this genus belongs, attained its maximum development during the Carboniferous period, both in Britain and America. No fewer than seven genera have been recognised in

America and 4 in Britain. In *Palæchinus* the interambulacral plates are not bevelled for overlapping as is the case with *Perischodomus*, *Oligophorus*, *Melonites*, and other genera. The modern representative, "*Calveria*" (*C. hystrix*) of Professor W. Thomson, was dredged in 445 fathoms water (2670 feet) in lat. 59° 38′ N., long. 7° 46′ W. *Calveria* differs from all known recent Echinoidea through the structure of the plates of the test, which overlap, instead of firmly abutting against each other, as in all other genera. Again, the plates composing the interambulacral overlap from the apical disk downwards towards the mouth, and those of the ambulacral area from the mouth upwards towards the apical disk, or in the reverse direction. This *ancient type* appears in the Chalk as *Echinothuria* (*E. floriformis*); and now, through the dredgings of the 'Porcupine,' we have proof of its continuity from the Cretaceous epoch.

Annelida.—Three genera, with four species, are known, two of which claim attention here, viz., *Tentaculites ornatus*, Sow., and *Cornulites serpularia*, Schloth. They have occurred in almost every locality since their first appearance in the Caradoc or Bala beds. *Tentaculites* ranges through the Caradoc everywhere except in Scotland; it is abundant in the Lower Llandovery of South Wales; but its maximum of development takes place in the May Hill Sandstones, where it is a marked feature in the fauna. It is sparingly exhibited in the Wenlock shales and sandstones, *Cornulites* having replaced it in these beds. *Tentaculites anglicus*, *T. ornatus*, and *T. tenuis* are also Ludlow species; and the long-lived *T. anglicus* either passes to the Middle Devonian slightly modified, or is replaced by Schlotheim's species, *T. Scalaris*.

Cornulites serpularius, *Tentaculites anglicus*, *T. ornatus*, and *Spirorbis Lewisii*, pass to the Wenlock.

The Cephalobranchiate or Tubicolar Annulosa (Annelida) play an important part in the life and distribution of the class through time. Their habits insure persistency, their structure security, and their bathymetrical ranges are such as to lessen their chances of modification through relative changes of land and sea. No form of the order Errantia, or Dorsibranchiata, has been clearly detected in the Llandovery rocks, although, doubtless, they existed, as many of the so-called fucoidal remains are only tracks of these annelids; and their presence has been demonstrated by Mr. G. J. Hinde through his discovery of the jaws of many species of the Polychæta in the Silurian, Devonian, and Carboniferous formations. In the Wenlock alone he has discovered the remains of 6 genera and 24 species; and in the Ludlow 2 of the same genera and 6 species. By careful sifting and preparation, the clays and shales of the still older rocks may yield a rich harvest of the remains of the Annulosa and soft-skinned Echinoderms.[1]

Crustacea.—The distribution of the Crustacea through the Lower Llandovery is more constant and universal than in any other Silurian deposit. *Calymene Blumenbachii*, *Encrinurus punctatus*, *Illænus*

[1] Q. J. G. S., vol. xxxvi. pp. 368-378.

Thomsoni, *Proëtus Stokesii*, and *Phacops Stokesii* occur in almost every locality, and all 5 pass to the Wenlock. *Illœnus œmulus*, *I. Bowmanii*, *I. Maccallumi*, *Phacops Weaveri*, *P. obtusicaudatus*, *Lichas laxatus*, and *Trinucleus concentricus* do not pass to any higher horizon than Upper Llandovery.

Brachiopoda.—The species in this class are more than double the number of those of any other in the Upper Llandovery rocks. Sixty-five species illustrate 13 genera. The geographical distribution of *Atrypa*, *Leptœna*, *Orthis*, *Pentamerus*, *Rhynchonella*, *Stricklandinia*, *Spirifera*, and *Strophomena*, in all 50 species, is complete through South Wales, Gloucestershire, Worcestershire, and Shropshire. These 8 genera include the mass of species (50 of the 65) that range through the chief known localities. No less than 36 species survive from the Lower Llandovery, and 41 of the 65 range into the Wenlock beds. As among the Crustacea, few species belong to the Upper Llandovery proper, showing how slight is the evidence afforded us for the separation of the Lower and Upper Llandovery. The stratigraphical unconformity is, however, completely borne out by a corresponding palæontological break. This is decisively seen through the Actinozoa, the Crustacea, the Brachiopoda, and the Pelecypoda. The Upper Llandovery rocks of the nine chief areas given below have yielded the following number of genera and species of Brachiopoda :—

Counties.	Genera.	Species.
Pembrokeshire	11	19
Caermarthenshire	12	38
Cardiganshire	none	none
Radnorshire	6	22
Gloucestershire	9	27
Worcestershire	11	35
Shropshire	13	13
Scotland	9	12
Ireland	10	19

Pelecypoda (Lamellibranchiata).—Considering the few species known in the Lower Llandovery (3), we have here a marked change in the greatly increased fauna of bivalve Mollusca, which have increased from the 3 species in the Lower Llandovery (*Pterinœa retroflexa*, *Mytilus mytilimeris*, and *Orthonota sulcata*) to 12 genera and 29 species. Only 3 species are known in Scotland, *Anodontopsis bulla*, *Pterinœa Sowerbyi*, and *Cardiola striata*, and 3 in Ireland, *Anodontopsis bulla*, *Pterinœa bullata*, and *Ctenodonta subcylindrica*.

Gasteropoda.—The distributional value of the Gasteropoda is through species of *Holopella*, *Acroculia*, *Rhaphistoma*, and *Turbo*. These forms, too, have a wide geographical distribution, Worcestershire, as before, possessing the greatest number (9); Ireland has also 9 species; while Caermarthenshire has 7. Six genera and 8 species pass to the Wenlock; they are *Acroculia haliotis*, *Euomphalus alatus*, *E. funatus*, *E. sculptus*, *Holopella obsoleta*, *Loxonema sinuosa*, *Murchisonia articulata*, and *Turbo tritorquatus*. No form occurs in the Upper Llandovery of Cardiganshire.

PLATE V.

UPPER SILURIAN FOSSILS.

1. *Acervularia ananas.* Wenlock Limestone.
2. *Arachnophyllum typus.* Wenlock Limestone.

2a. *Arachnophyllum typus.* Showing calicular development, or budding from a single corallite.

3. *Cyathophyllum truncatum.* With single corallite showing calicular development. Wenlock Limestone.
4. *Cyathophyllum articulatum.* Wenlock Limestone.
5. *Omphyma turbinata.* Exhibiting the characteristic rootlets springing from the epitheca or wall.

5a. *Omphyma turbinata,* and section of calice showing the four fossulæ.

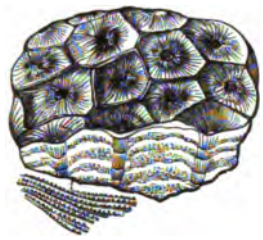
6. *Do. do.* Cut through to show the tabulæ, and arched vesicular wall tissue of the coral.
7. *Cystiphyllum vesiculosum.* Section showing cellular structure.
8. *Ptychophyllum patellatum.* Wenlock Limestone and shale.
9. *Sphærexochus mirus.* Woolhope and Wenlock rocks.
10. *Cheirurus bimucornatus.* Ranges from the Caradoc rocks up to the Aymestry Limestone.
11. *Encrinurus punctatus.* Caradoc to Upper Ludlow.
12. *Encrinurus variolaris.* Wenlock rocks.
13. *Phacops Downingiæ.* Upper Llandovery to Upper Ludlow, abundant.
14. *Acidaspis Brightii.* Caradoc to Wenlock.
15. *Acidaspis Barrandii.* Wenlock Limestone.
16. *Cyphaspis megalops.* Caradoc to Ludlow.
17. *Proetus latifrons.* Upper Llandovery to Wenlock Limestone.
18. *Favosites Gothlandicus.* Wenlock Limestone.

18a. Enlarged section of corallite, walls showing perforations.

PLATE V.

UPPER SILURIAN FOSSILS.

5



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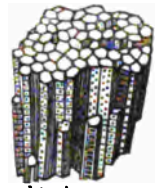

18

18a

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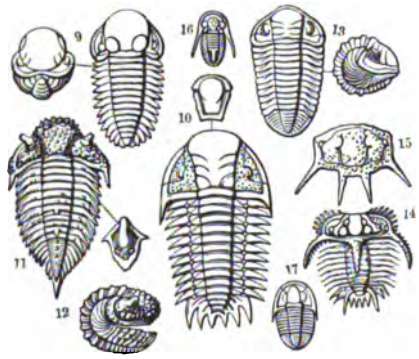


9 16 13 10 15 14 11 17 12

Pteropoda.—In the Upper Llandovery. *Conularia cancellata*, the only known species, occurs in Gloucestershire and Shropshire, and is met with in no other formations or localities in Britain. The more abundant *C. Sowerbyi* is Lower Llandovery, Wenlock, and Ludlow. It is questionable if *C. cancellata* is really a British species or only a variety of *C. Sowerbyi*.

Heteropoda.—*Ecculiomphalus* (*Cyrtolites*) and *Bellerophon*, the former having 2 species (*E. lævis* and *E. scoticus*), the latter 9, range pretty equally through the Upper Llandovery rocks, *B. dilatus*, *B. trilobatus*, and *B. carinatus* having the widest or most extended geographical distribution. The rarer forms are *Ecculiomphalus scoticus*, *Bellerophon subdecussatus*, *B. wenlockensis*, and *B. obtectus*; but only one species, *B. carinatus*, seems to have been Lower Llandovery. These Pelagic or oceanic Mollusca, especially the family Atlantidæ, have no fixed habitat, their distribution being quite independent of the nature of the sea-bottom, so that the Heteropoda of the Silurian, Devonian, and Carboniferous periods occur indifferently in sediments of the most varied lithological character. The great *Porcellia* (*P. Woodwardii*), of the Middle Devonian, or the two species, *P. striata* and *P. Symondsii*, are met with in all kinds of deposits throughout the history of the genus, of which 12 or 14 species range from the Devonian to the Trias, Belgium having also afforded many forms.

Cephalopoda.—*Actinoceras*, *Cyrtoceras*, *Lituites*, *Phragmoceras*, *Tretoceras*, and *Orthoceras*, are all Upper Llandovery genera. *Phragmoceras compressum* and *Cyrtoceras approximatum* have but local geographical distribution. The last-named species occurs in the Upper Llandovery of Malvern only; *P. compressum* the same, and is of doubtful occurrence in the Ludlow rocks. We have seen that the Caradoc rocks of Shropshire have not yielded a single species; but here, the Upper Llandovery of the same county contains 3 genera and 9 species; yet 8 genera and 47 species occur in the Caradoc rocks generally. This fact tends to prove the shallowing of the Caradoc sea and slow elevation of the sea-bed through the latter part of the Caradoc period, and the time represented by the deposition of both the Lower and Upper Llandovery series. Four genera and 9 species pass to the Wenlock. Ireland yields only 2, *Orthoceras coralliforme* and *O. subgregarium*. Taking South Wales generally, only 6 species are there known, and these represent 4 genera—*Actinoceras*, *Lituites*, *Orthoceras*, and *Tretoceras*.

The Upper Llandovery rocks of Scotland also give us 4 species, 3 *Orthocerata* and 1 *Phragmoceras* (*P. compressum*).

We therefore find that, out of the whole fauna of the Upper Llandovery rocks, numbering 240 species, only 91 are confined to them and do not pass higher. The following table shows numerically the special Upper Llandovery fauna:—

*

Protozoa	2	species
Actinozoa	10	,,
Echinodermata	3	,,
Crustacea	8	,,
Polyzoa	3	,,
Brachiopoda	22	,,
Pelecypoda	11	,,
Gasteropoda	17	,,
Pteropoda	1	,,
Heteropoda	5	,,
Cephalopoda	9	,,
	91	

The following are the most characteristic fossils of the Upper Llandovery or May Hill group, which are also numerically abundant.

ACTINOZOA.—*Petraia elongata.*
ECHINODERMATA.—*Palæchinus Phillipsiæ.*
CRUSTACEA.—*Acidaspis calliparcos.*
BRACHIOPODA.—*Atrypa hemispherica, Lingula crumena, L. parallela, Pentamerus oblongus,* and *P. undatus, Stricklandinia* (*Pentamerus*) *lens, S. lirata, Meristella* (*Rhynchonella*) *angustifrons.*
PELECYPODA.—*Pleurorhynchus* (*Conocardium*) *pristis, Ctenodonta* (*Arca*) *Eastrori, Pterinæa bullata.*
GASTEROPODA.—*Cyclonema quadristriata, Euomphalus prænuntius, Macrocheilus fusiformis.*
CEPHALOPODA.—*Cyrtoceras approximatum, Lituites undosus, Orthoceras Barrandii,* and *Tretoceras bisiphonatum.*

The accompanying table shows the faunal value or generic and specific relationship between the Caradoc and Llandovery groups :—

TABLE XIV.

Llandovery Fauna.		Classes.	Caradoc.		Llandovery.	
Upper Llandv. Genera.	Lower Llandv. Genera.		Genera.	Species.	Species passing to Lower Llandv.	Species passing to Upper Llandv.
1	...	Plantæ	...	...	...	...
2	3	Protozoa	9	10	3	none
16	12	Actinozoa	20	40	20	17
4	7	Hydrozoa	21	38	1	...
5	2	Echinodermata	15	32	2	1
11	13	Crustacea	37	146	16	17
2	2	Polyzoa	7	21	4	6
3	2	Annelida	11	15	2	2
13	10	Brachiopoda	15	109	33	27
12	3	Pelecypoda	16	76	3	7
13	9	Gasteropoda	14	53	10	16
1	1	Pteropoda	3	10	1	2
2	1	Heteropoda	3	17	1	4
6	3	Cephalopoda	8	47	7	9
...	...	Pisces	...	...	...	...
91	68		179	614	103	108

CHAPTER XIV.

THE WENLOCK GROUP.

THIS great marine series is divided into *Upper Wenlock* and *Lower Wenlock*—the Upper embracing the *Wenlock limestone and shale;* the Lower the *Woolhope limestone*, the *Denbighshire grits*, and *Tarannon shales.*

Faunal Value. — The *Actinozoa*, *Echinodermata*, *Crustacea*, *Brachiopoda*, and *Pelecypoda* are the chief classes in the Wenlock group, and are largely represented. The whole Wenlock fauna comprises 171 genera and 536 species.

The Actinozoa,	25	genera and	76	species.
„ Echinodermata,	28	„	68	„
„ Crustacea,	27	„	78	„
„ Brachiopoda	22	„	101	„
„ Lamellibranchiata,	16	„	44	„
The remaining 8 classes,	53	„	169	„
	171		536	

The Fauna of the subdivisions, or the distribution of the species through the 4 horizons, is as follows:—

The Wenlock limestone and shale,	161	genera and	473	species.
„ Woolhope beds	67	„	137	„
„ Denbighshire grits	39	„	57	„
„ Tarannon beds	25	„	54	„

Seventy-one genera and 126 species pass to the succeeding Lower Ludlow, 38 genera and 53 species range into the Aymestry limestone, and 51 genera and 87 species pass to the Upper Ludlow.

The Wenlock series is estimated to be about 3000 feet thick.

Geographical Distribution of Species.—The geographical distribution of the species through the 5 following areas is as follows:—

North Wales,	47	genera and	98	species.
South Wales,	68	„	160	„
Westmoreland,	3	„	16	„
Scotland,	29	„	45	„
Ireland,	45	„	86	„

(1.) **The Tarannon Shales or Rhayader Slates.** — These rocks underlie the Denbighshire grits and sandstones. They are the pale-coloured earthy slates, or "*Paste Rock*," of Sedgwick, and the pale-grey, smooth, fine-grained, slate-rock, underlying the Denbighshire grits and sandstones, to which Professor Ramsay gave the name of "*Tarannon Shale*," from the valley and river of that name, between Llanidloes and Dinas Mowddry. Professor Sedgwick has described them under the name of "Rhayader Slates."[1] These shales are about 1500 feet thick, and may be traced from South Wales into North

[1] Q. J. G. S., vol. iii. p. 153.

Wales; forming, either with or without the Upper Llandovery or May Hill beds, a marked physical separation between the Lower and Upper Silurian series. The Tarannon beds overlie the Upper Pentamerus, or Llandovery beds near Builth, and underlie the Denbighshire grits. They are not known out of Wales.

Distribution.—These singular rocks are exposed in a narrow and nearly unbroken line of country, from the estuary of the Conwy, to near Llandovery, rising from beneath the western base of the Wenlock shale and Denbighshire grits. They are all well shown west of Builth in Radnorshire, where they are conspicuously unconformable to the Lower Llandovery rocks. On the north-west of the Berwyns these "pale shales" separate the Denbighshire grits from the underlying Bala beds. North of Llangollen, along the southern flanks of the Cyrn-y-brain range, the Tarannon beds are conspicuous. These shales, when the Upper Llandovery are absent, form the lowest part of the Upper Silurian rocks of North and South Wales. It seems probable that the strata which lie between the top of the Caradoc or Bala beds and the base of the Wenlock shale were deposited during a long period of time, and under frequent oscillations of the relative levels of the land and sea, movements which succeeded the long and continuous deposition or sedimentation of the Bala beds, and preceded the formation of the Wenlock group.

Fauna of the Tarannon Shales.—The fauna of these shales is small, comprising only 25 genera and 54 species; of the 13 classes only 6 are recognised, viz., the *Echinodermata*, *Annelida*, *Polyzoa*, *Pteropoda*, *Heteropoda*, and the *Cephalopoda*, the remaining seven classes having no representative.

The Hydrozoa with 5 genera and 23 species, and the Brachiopoda with 10 genera and 15 species, comprise nearly the whole known fauna, which is essentially that of the Wenlock beds, the characteristic species being—

HYDROZOA.—*Monograptus priodon.*
ACTINOZOA.—*Favosites aspera, F. fibrosus, F. Gothlandica, Petraia bina, P. subduplicata.*
CRUSTACEA.—*Acidaspis Barrandii, Beyrichia klædeni, Calymene Blumenbachii, Cheirurus bimucronatus, Illænus Thomsoni, Phacops caudatus, P. Downingiæ,* and *P. Stokesii.*
BRACHIOPODA.—*Atrypa reticularis, Chonetes minima, C. implicata, Leptæna transversalis, L. symondsii, Orthis biloba, O. elegantula, O. hybrida, Pentamerus rotundus, Rhynchonella decemplicata, R. nucula, Spirifera elevata, S. exporrecta, Strophomena pecten, and S. rhomboidalis.*
LAMELLIBRANCHIATA.—*Pterinæa planulata, P. retroflexa.*
GASTEROPODA.—*Acroculia haliotis.*

(2.) **Denbighshire Grits.**—These rocks, with the Tarannon shales, constitute the base of the Lower Wenlock series in North Wales. Locally they occupy the place of the Woolhope limestone in Shropshire and Herefordshire, but contain Wenlock fossils.[1]

[1] These beds were first noticed and described by Mr. Bowman in 1841, as coarse flags with Orthocerata, and included by him as a subordinate part of the Upper Silurian rocks.—(Brit. Assoc. Reports, 1841). In 1842, Mr. D. Sharpe

The base of the Wenlock series in Shropshire and the border counties contains a peculiar limestone, which in places becomes or passes into a shale. This limestone differs considerably in its fauna from the overlying Wenlock limestone, yet the general facies is the same. One hundred and twenty species are known to occur in these grits. In the Denbighshire grits there are 57; and in the Tarannon shales, 34. The Wenlock, taken as a whole, numbers 443 species.

It is highly probable that the Denbighshire grit and flagstones, and Coniston grit and flagstone, may be of the same age, or represent each other in the North Wales and Lake district.

In Westmoreland, the upper portion of the "Coniston" or "Brathay flag" contains many fossils in common with the Denbighshire flagstones; and the overlying thick Coniston grits possess fossils resembling those of the Denbighshire flags, and Coniston. How far they are identical it is difficult to say. Professor Sedgwick and Mr. Salter believed that the flagstones of Balmae, Kirkcudbright, belong to the Lower Wenlock, and are the equivalents of the Denbigh flags.

The maximum thickness of the Denbigh grits is about 3000 feet, and they occupy a broad and almost continuous strip of country from the estuary of the river Conwy to Melynllyn, near Llanddewi and Ystrad Enny in Radnorshire; they also occur over a considerable breadth of country, lying in a trough, east of Bala Lake; while, between Llangollen and Corwen, they overlie the Tarannon shales. North of Builth (Radnorshire) they almost die out.[1]

Fauna of the Denbighshire Grits.—The fauna of these grits may be collected near Merchlyn-Maur, Plas Madoc, near Llanrwst, Moel Seisiog, and Mwdwl Eithen, near Pentre Voelas and Craighir.[2]

The fossils are those of the Wenlock shale, and the most characteristic are—

Favosites (Stenopora) fibrosa, Phacops Downingiæ, Calymene Blumenbachii, Strophomena rhomboidalis, Chonetes striatella, Leptæna transversalis, Spirifera elevata, Actinocrinus pulcher, Phragmoceras nautileum, Bellerophon carinatus, B. expansus, Loxonema elegans, and *Murchisonia articulata.*

(3.) **Woolhope Limestone and Shale.**[3]—This is the lowest calcareous member of the Upper Silurian rocks, and derives its name from the development of the strata at Woolhope near Hereford. The beds are also well observed on the western flanks of the Malvern Hills and May Hill near Gloucester, Walsall and Great Bar in Staffordshire, and also in Radnorshire. Nowhere, however, are the rocks so well

observed these grits at Mallwyd, and described them as part of the Wenlock series.—(Proc. Geol. Soc., vol. iv. p. 12). In 1843, Professor Sedgwick described and correctly placed them at the base of the Denbighshire flagstones, their lower part being therefore the equivalent of the Wenlock shale.

[1] See Mem. Geol. Survey, vol. iii., Geol. North Wales, pp. 12, 13.

[2] *Ibid.*, pp. 210–212, 222.

[3] For sometime identified with the "Holles Limestone," and termed the "Caradoc" or "Woolhope" Limestone and Shale; they are, however, on different horizons.

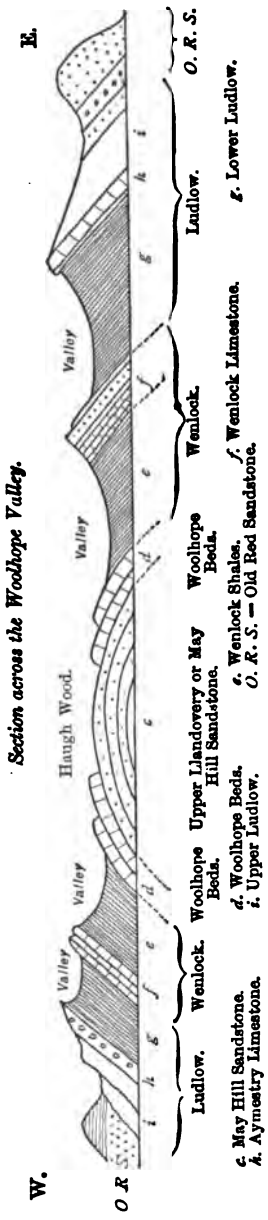


Fig. 2.

developed as at Woolhope, mantling round and resting upon the central dome composed of the "May Hill, or Upper Llandovery Sandstone," in the centre of the most symmetrical valley of elevation in the British Islands. The Woolhope beds (*d*) form almost a conformable cover to the central Upper Llandovery or May Hill Sandstone anticlinal (*c*); and dip from it to all points of the compass, underlying the Wenlock Shale (*e*) and the superincumbent Wenlock Limestone (*f*). These in their turn are all seen to pass under the Ludlow Rocks (*g h i*) and the Old Red Sandstone (*k*).

The entire series of the Upper Silurian Rocks, from base to summit, are exposed on both sides, and all round the Central Haugh Wood Dome, in whichever way we examine them. No more perfect piece of geological sequence can be examined in Europe; this arises from the exposed position of the various strata around a common centre (*c*), caused by denudation following elevation, and by the subsequent excavation of the shales (*e* and *g*). The Haugh Wood Dome of May Hill Sandstone, and its partial cover of the Woolhope Limestone, is margined or surrounded by two encircling ridges of limestone (Wenlock and Aymestry), and two well-defined valleys in the Wenlock Shales (*e*) and Lower Ludlow Beds (*f*).

Fauna of the Woolhope Limestone.—Equally instructive with its pure geology is the fossil fauna contained in the series of formations comprising the Woolhope Valley, from every bed in which the characteristic fossils may be collected, ranging from the "Upper Llandovery or May Hill" series to the top of the "Upper Ludlow" inclusive.

The central axis or dome yields the typical Pentameri [*P. (stricklandinia) lens, P. lirata*] of the Llandovery Rocks, with *Leptæna transversalis, Atrypa reticularis, Strophomena depressa, Petraia bina*, and other species characteristic of the horizon.

The overlying shales and limestones are altogether different, being dark-grey argillaceous and calcareous lime-

stones, strongly veined by pink and white veins, or strings of calcite. Thick beds of tough, impure, earthy limestone, not exceeding 40 feet in thickness, constitute the mass and yield a peculiar set of fossils.

The Woolhope series, as a whole, contain about 141 species, mostly related to the fauna of the succeeding Wenlock Shale and Limestone, which have yielded 443 species. The following 11 classes are represented by the 141 species:—

	Species
Protozoa	2
Actinozoa	26
Echinodermata	2
Annelida	3
Crustacea	25
Polyzoa	4
Brachiopoda	59
Pelecypoda	6
Gasteropoda	8
Pteropoda	3
Cephalopoda	3
	141

Palæontology of the Woolhope Beds.—The most important Crustacea (Trilobita) are—*Illœnus* (*Bumastus*) *Barriensis*, *Homalonotus delphinocephalus*, *Calymene Blumenbachii*, *Phacops caudatus*, *P. longicaudatus*, and *P. Stokesii*. *Graptolithus priodon* occurs in the shales. *Lingula Lewisii*, *Meristella didyma*, *Orbiculoidea Forbesii*, *Orthis Mullockensis*, *Pentamerus galeatus*, *Rhynchonella brevirostris*, *R. deflexa*, *R. navicularis*, *R. Stricklandi*, and *R. Wilsoni* are the chief Brachiopoda.

The Pelecypoda are few. *Pterinea Sowerbyii*, *Cardiola striata*, and *Mytilus mytilimeris* are somewhat abundant. *Euomphalus sculptus*, *E. carinatus*, *Acroculia prototypa*, typify the Gasteropoda. *Bellerophon bilobatus*, *B. dilatatus*, belong to the Heteropoda. *Actinoceras baccatus*, *Lituites cornu-arietes*, and *Orthoceras conicum*, are common Cephalopoda.

Physical Conditions.—In Radnorshire the beds are identical with those of Woolhope. In the Malvern, May Hill, and Huntly Hill districts, the beds are modified both in lithological characters and zoological contents.

On the western side of May Hill and along the Wenlock Edge, the limestone is nodular, the nodules being distributed through shales which probably are the equivalent of the Wenlock shales.

At Crumpend Hill, the Wych, and Netherton Valley near Eastnor, the Woolhope beds dip away or underlie the Wenlock series. The construction of the Malvern tunnel revealed a thick series of Woolhope shales resting upon the "Pentamerus" or Llandovery beds, and below the Woolhope limestone.[1]

Their conformability to the underlying May Hill group and its

[1] These occupy the position of the Tarannon shales of the Geological Survey.

upper member, clearly shows that either the Tarannon shales and Denbighshire grits did not extend into that area, or that the Woolhope beds (shales) may be the equivalent in time of these South and North Welsh beds.

Woolhope Fauna.—A most abundant Lower Wenlock or Woolhope fauna occurs in the Woolhope shales, the following being some of the characteristic species :—

Illænus Barriensis, Encrinurus punctatus, Phacops Downingiæ, Sphærexochus mirus, Lingula Lewisii, Rhynchonella navicula, R. Wilsoni, R. borealis, &c., Pentamerus linguifer, P. rotundus, Pterinæa Sowerbyii; Cardiola striata, and *Bellerophon dilatatus.*

The Cephalopoda are few; the Protozoan genus, Ischadites, abounds in places. These Woolhope beds, under varied lithological conditions, can be correlated through organic remains in many localities, and over an extensive area.

At Great Barr or Barr Beacon, near Walsall, Hay Head, and other localities, where the Wenlock rocks are fully exposed, the same conditions (on the whole) prevail, and it may be said that the great calcareous group of the Upper Silurian rocks commences here through the abundance of life.

Sixty-seven genera and 141 species occur in the Woolhope series, chiefly represented by 3 classes, viz., the *Actinozoa*, the *Crustacea*, and the *Brachiopoda*. These three groups united comprise 47 genera and 107 species out of the 67 and 141 named. This clearly shows the bathymetrical condition of the sea-bed during the deposition of the early portion of the Wenlock group, and the great increase in species in the succeeding and deeper sea fauna of the Wenlock.

Characteristic Fossils.—The most characteristic and peculiar fossils of the Woolhope beds are—

ACTINOZOA.—*Cyathophyllum angustum, Goniophyllum pyramidale, Petraia bina, Syringopora bifurcata,* and *Thecia swindernana.*

ECHINODERMATA.—*Eucalyptocrinus polydactylus,* and *Pisocrinus pilula* (the only two occurring in the Woolhope, whereas in the Wenlock proper 28 genera and 65 species are known).

ANNELIDA.—*Cornulites vupularius* and *Spirorbis Lewisii.*

CRUSTACEA.—*Illænus Barriensis, Lichas verrucosus, Phacops Muscheni,* and *Staurocephalus Murchisoni.*

POLYZOA.—*Ptilodictya lanceolata, Fenestella scalpellum.*

BRACHIOPODA.—*Athyris Grayii, Leptæna orbigniana, Lingula Lewisii, Obolus Woodwardii, O. hybrida, Pentamerus undatus, Rhynchonella deflexa,* and *R. Wilsoni.*

PELECYPODA (LAMELLIBRANCHIATA).—*Pterinæa retroflexa, P. sowerbyii, P. planulata, Cardiola striata, Ctenodonta sulcata,* and *Mytilus mytilimeris.*

GASTEROPODA.—*Acroculia haliotis, A. prototypa, Euomphalus carinatus, E. sculptus, Trochus cælatulus,* and *Turbo tritorquatus.*

HETEROPODA.—*Bellerophon bilobatus, B. dilatatus, B. trilobatus.*

CEPHALOPODA.—*Actinoceras baccatum, Lituites cornuarietes, Orthoceras angulatum,* and *O. conicum.*

PLATE VI.

UPPER SILURIAN FOSSILS.

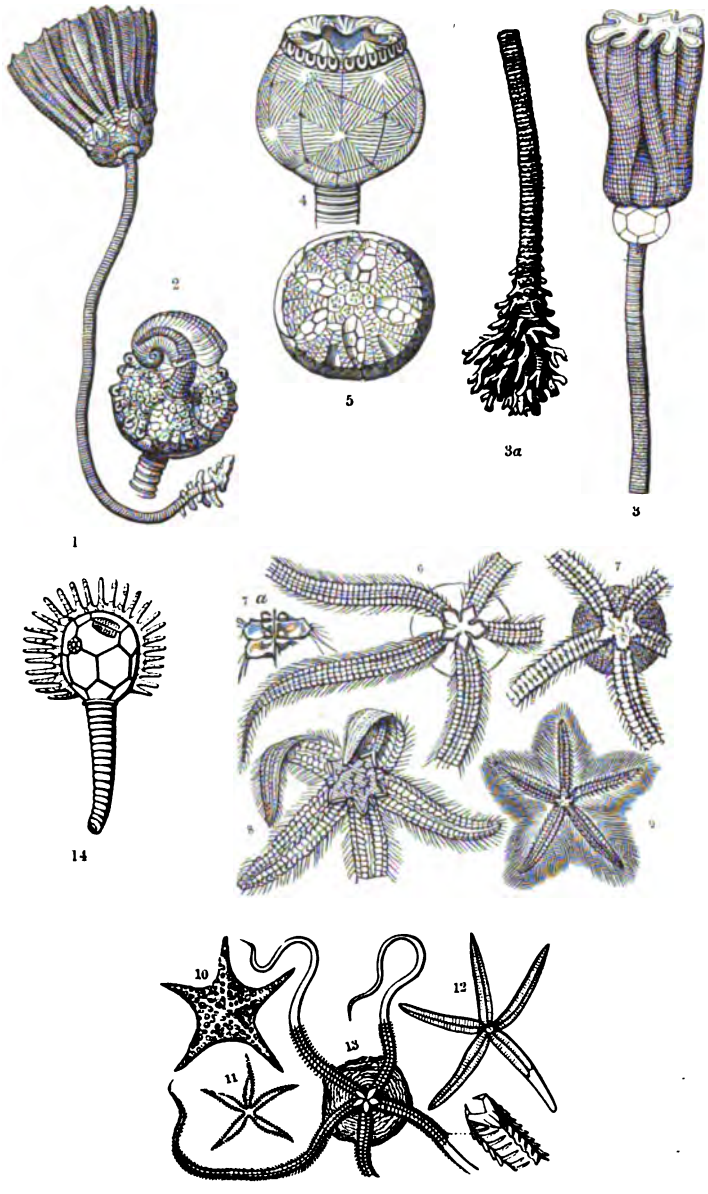
PLATE VI.

UPPER SILURIAN FOSSILS.

1. *Marsupiocrinus cælatus* (Phill.) Wenlock, Limestone, Dudley, &c.
2. *Proboscis* of *Marsupiocrinus cælatus*. "Inserted in the shell of *Acroculia haliotis*." Dudley and Wenlock Edge.
3. *Crotalocrinus rugosus* (Miller). Wenlock Limestone Dudley, showing the arms above the small pelvis. 3*a*. Stem with rootlets.
4. *Crotalocrinus rugosus*. Stomach plates removed, to show the base of the many-fingered arms. Dudley, &c.
5. The flat stomachal surface, showing branching arms from their bases.
6. *Protaster Miltoni* (Salt.) Lower Ludlow rocks. Leintwardine.
7. *Protaster*. Showing base or ventral side.
8. *Palæocoma Marstoni* (Salt.) Lower Ludlow rocks. Leintwardine.
9. *Palæocoma Colvini* (Salt.) Lower Ludlow.
10. *Palasterina primæva* (Forbes). Ludlow rocks.
11. *Palæaster hirundo* (Forbes). Upper Ludlow. Kendal.
12. *Palæaster Ruthveni* (Forbes). Upper Ludlow. Kendal.
13. *Protaster Sedgwicki* (Forbes). Upper Ludlow. Kendal.
14. *Pseudocrinites bifasciatus* (Pearce). Wenlock Limestone, Dudley, &c. After Murchison, "*Siluria*," 4th ed.

PLATE VI.

UPPER SILURIAN FOSSILS.



CHAPTER XV.

WENLOCK LIMESTONE.

Couche à *Calymene Blumenbachii* d'Herbray (Loire Inf.) et Schistes à *Cardiola interrupta.* (France.)
Étage E. 1, 2, Calcaire Inférieur, Barrande. (Bohemia.)
Regio E. *Cryptonimorum* d'Angelin.
Calcaire à Ortho cératites de Gothland et de Malmœ d'Angelin. (Scandinavia.)
Onondaga salt group and Niagara group, Upper part of Ontario Division, } America.

Upper Wenlock—Wenlock Limestone and Shale.

Wenlock Limestone.
= Hay Head or Barr Limestone.
= Dudley Limestone.

THIS limestone, commonly known as the "Dudley Limestone," forms a continuous ridge or low escarpment at Wenlock in Shropshire ("The Wenlock Edge"), ranging for about 20 miles from the S.W. to the N.E. The Aymestry Limestone lies above it, nearly one mile to the east, and in a parallel escarpment.

The Wenlock "edge" (ridge, escarpment, or elevated line of country) is due to the solidity of the limestone which forms the central portion of the Wenlock series, the shales above and below being of a soft nature and easily denuded.

Wenlock Shale.—The lower portion of this group, or the Wenlock shale, is usually dark grey, sometimes nearly black in colour, containing many calcareous concretions, and in places attaining to 1200 and 1400 feet in thickness. The Wenlock Limestone rarely exceeds 300 feet, and is composed of thick masses of sub-crystalline or highly crystalline limestone, in places literally filled with Corals, Crinoidea, Polyzoa, and Brachiopoda.

The Wenlock Limestone and shales are admirably shown in all the country between Aymestry and Ludlow, along the "Wenlock Edge," to Benthal Edge, near Coalbrook Dale, the Castle Hill and Wren's Nest near Dudley, near Walsall in Staffordshire, the west side of the Malvern Hills, May Hill, and in the neighbourhood of Usk, in Monmouthshire. In places (and especially in the Malvern area) this limestone is oolitic. At all the above localities the limestone possesses a rich fauna, unsurpassed in variety of species and profusion of extinct life. The Wenlock Limestone of Woolhope constitutes the great feature in the second ridge. (See fig. 2, p. 110.)

Characteristic Wenlock Fossils.—It is difficult to name any *special* locality where the species characteristic of the limestones may be obtained, so numerous and abundant are they everywhere; but Wenlock Edge, Benthall Edge, Gliddon Hill, the Gorge of the Lugg, near Aymestry, Malvern, Usk, Donnington (Woolhope), and Dudley, are places where almost every known species may be found. The

most typical or characteristic of the Wenlock limestone are the following, nearly restricted to it. (See Plate V. for many species.)

ACTINOZOA.—*Heliolites interstinctus, Acervularia luxuriana, Cystyphyllum siluriense, Goniophyllum Fletcheri, Omphyma turbinatum, Strombodes typus,* and *Favosites gothlandica.*

ECHINODERMATA (CRINOIDEA).—*Actinocrinus simplex, Crotalocrinus rugosus, Cyathocrinus goniodactylus, Eucalyptocrinus decorus, Glyptocrinus expansus,* and *Marsupiocrinus cælatus.*

CYSTIDEA.—*Apiocystites pentrematoides, Prunocystites Fletcheri,* and *Pseudocrinites magnificus.*

ASTERIADÆ.—*Lepidaster Grayii.*

CRUSTACEA.—*Acidaspis coronatus, Deiphon Forbesii, Homalonotus delphinocephalus, Lichas Barrandii, Phacops longicaudatus,* and *Staurocephalus Murchisoni.*

CIRRIPEDIA.—*Turrilepas Wrightianus.*

POLYZOA.—*Ceriopora oculata, Discopora favosa, Fenestella Lonsdalei,* and *Retepora infundibulum.*

BRACHIOPODA.—*Athyris depressa, Crania Siluriana, Meristella circe, Orthis Walsallensis, O. Lewisii, Pentamerus linguifer, Retzia Salteri, Rhynchonella brevirostris, R. Lewisii, R. Stricklandi,* and *Strophomena Dayi.*

PELECYPODA.—*Pterinea asperula, Clidophorus planulatus, Modiolopsis complanata, Pleurorhynchus (conocardium) æquicostatus,* and *Mytilus Chemungensis.*

GASTEROPODA.—*Cyclonema ventricosa, Eunema cirrhosus, Euomphalus discors, E. rugosus,* and *Murchisonia balteata.*

HETEROPODA.—*Bellerophon Wenlockensis,* and *Theca anceps.*

CEPHALOPODA.—*Orthoceras distans, O. marloense, O. canaliculatum, Lituites Biddulphi,* and *Actinoceras Brightii.*

Nearly all the above species are confined to the Wenlock limestone and its associated shales. Few, if any, are Llandovery or Woolhope, and few pass to the Ludlow rocks.

Upper Wenlock: Wenlock Shale.—The Wenlock shale is the most persistent member of the Wenlock formation. The associated Wenlock limestone, strictly speaking, is an accidental deposit in and between the shales due to shallow-water conditions, and consists of an assemblage of fossil invertebrata of surpassing beauty and perfection, certain groups of which culminated in the Wenlock seas of Europe and America.

The chief development of this shale is seen in exposures on the banks of the river Severn, near Iron Bridge and Coalbrook Dale, along the flanks and escarpment of the Wenlock Edge, from thence to Caer Caradoc, occupying the broad vale of Apes Dale, near Dudley, and in the Malvern, Woolhope, and Tortworth areas. In Denbighshire, west of Llangollen, it is present in the form of highly-metamorphosed, hard, slaty, and fine-grained, calcareous sandstones, containing but few fossils. It must be borne in mind that, in consequence of the different physical conditions under which these shales have been deposited, they now assume lithologically in different localities many aspects. The organic remains, consequently, vary much with these geographical conditions.

In North Wales and Westmoreland the Wenlock series is chiefly shaly and indurated; in places it passes even into slate. In South Wales it consists of shales and sandstone; we therefore find that the

more sandy strata contain species which range into, and are abundant in, similar deposits in the succeeding Ludlow group.

Fauna of the Wenlock Shale.—The fauna of the Wenlock shale numbers 160 species in the following 10 groups:—

Actinozoa	24	species.
Annelida	2	„
Crustacea	21	„
Polyzoa	3	„
Brachiopoda	65	„
Pelecypoda	29	„
Gasteropoda	6	„
Heteropoda	2	„
Pteropoda	2	„
Cephalopoda	6	„
	160	

It is evident, from the above analysis, that the facies of life in the Wenlock shale is characteristic of moderately deep sea sedimentation. This view is confirmed by the Actinozoa, Brachiopoda, and Crustacea, and the deduction is also favoured by the few known Gasteropoda. *Orthis*, *Leptæna*, *Atrypa*, *Rhynchonella*, *Strophomena*, and *Pentameri* are the chief Brachiopoda. The Cephalopoda are a peculiar group, and are not equally distributed in space, being mostly confined to Denbighshire, where they are rather abundant. *Lituites articulatus*, *L. giganteus*, and *L. Biddulphi* are not common forms. Highly ornamented species of Trilobites, *Encrinurus punctatus*, *E. variolarius*, *Calymene tuberculosa*, *Cheirurus bimucronatus*, *Acidaspis Brightii*, and others, are abundant in places.

The Actinozoa number 24 species, and vary little from those of the Wenlock limestone. Both the rugose and tabulate corals are well represented; amongst the former are *Acervularia*, *Arachnophyllum*, *Cyathophyllum*, *Omphyma*, and *Ptychophyllum*; whilst the Tabulata are represented by *Alveolites*, *Favosites*, *Halysites*, *Syringopora*, &c, and here and there by *Graptolithus priodon*, in some places abundant. The Wenlock shale is upwards of 600 feet thick.

Palæontology of the Wenlock Rocks.

We have stated that 58 genera and 125 species are common to the Wenlock rocks and the Upper Llandovery; in other words, these 125 species pass up from the Llandovery to the Wenlock formation. Next to the Caradoc and Bala, the Wenlock group, embracing the Tarannon Shales, Denbighshire Grits, Wenlock and Woolhope beds, possesses the largest Silurian fauna; it numbers 168 genera and 530 species. Eight groups or classes out of the fourteen furnish the majority of the species, in each case attaining their maximum in the Wenlock Limestone.

Protozoa.—*Cliona prisca* and *Spongarium Edwardsii* are both Denbighshire-grit species, the latter being also Wenlock and Ludlow; *Cnemidium tenue* occurs in the Wenlock only, and *Ischadites Grind-*

rodi in the Woolhope; the other well-known species, *I. Kœnigi*, has a wider range both in time and space.

Hydrozoa.—The Wenlock rocks (assuming the Tarannon and Denbighshire beds to be at their base) have yielded 6 genera and 30 species. Stratigraphically they occur chiefly in the Tarannon beds, or probably the Denbighshire Grits. So far as we know, there are none in the Woolhope beds.

Actinozoa.—At no period through Palæozoic time was there so large and rich a Cœlenterate fauna as during the Wenlock; numerically the Middle Devonian about equalled the Wenlock species in number, the genera being in both deposits much the same. The Wenlock rocks yield 25 genera and 76 species.

The Tarannon species are *Favosites asper*, *F. fibrosus*. *F. gothlandica*, *Petraia bina*, and *P. subduplicata*. The four Denbighshire-grit species are also *Favosites aspera*, *F. fibrosus*, *Petraia subduplicata*, and *Syringopora serpens*. The upper members of the Lower Wenlock (the Woolhope beds) yield 16 genera and 26 species.

Echinodermata.—Compared with the Upper Llandovery, the Wenlock sea must have been highly favourable to the development of the Echinodermata (crinoidea); for 60 of the 68 known species were new appearances in the British area. Many are American; 65 of the 68 are Wenlock Limestone; no species is known in Scotland, and only one in Ireland (*Actinocrinus Wynnei*); only one species (*Actinocrinus pulcher*) occurs in the Tarannon Shale of N. Wales, and 2 in the Woolhope (*Eucalyptocrinus polydactylus* and *Pisocrinus pilula*).

We should expect that out of so large a fauna many species would pass to the higher divisions of the Upper Silurian, but only 4 genera and 6 species pass to the Lower Ludlow. These are *Actinocrinus pulcher*, *Ichthyocrinus pyriformis*, and *I. M'Coyanus*; *Pseudocrinites magnificus*, *P. quadrifasciatus*; and *Rhophalocoma pyrotechnica*. *Ichthyocrinus pyriformis* is the only species occurring in the Aymestry Limestone. No less than 20 new genera made their first appearance, and 17 are confined to the Wenlock rocks; the 4 genera that pass to the Ludlow are *Ichthyocrinus*, *Taxocrinus*, *Pseudocrinites*, and *Rhophalocoma*. This marked and sudden addition to the 3 orders of the Echinodermata can only be explained upon the theory of migration from some prolific area; *whence* it is difficult to suggest; but the great development of the Crinoidea, Cystidea, &c., in N. America, and the manifest resemblance, if not identity, of the faunas in the two areas, would lead us to surmise that it was from the west rather than from Europe that the Wenlock sea derived these Crinoids.

Annelida.—No other British Palæozoic strata possess so many species of Annelida; they number 35. The discovery of this exuberance in the Wenlock beds is due to the researches of one naturalist,[1] through whose careful investigations no less than 6 new genera and 24 new species have been added to the Annelidan group of the Wenlock. Four species, *Helminthites*, sp., *Serpulites dispar*, *S. longissimus*, and *Spirorbis Lewisii*, pass to the Lower Ludlow, and 8 to the

[1] G. J. Hinde, Q. J. G. S., vol. xxxvi. pp. 368-378.

Upper, viz., *Cornulites serpularius*, *Serpulites dispar*, *S. longissimus*, *Tentaculites anglicus*, *T. ornatus*, *Trachyderma squamosa*, and 2 species of *Arabellites*.

Crustacea.—Ten new genera appear here for the first time; they are—*Turrilepas*, *Æchmina*, *Cyphaspis*, *Deiphon*, *Eurypterus*, *Hemiaspis*, *Pterygotus*, *Thilipsura*, *Cythere*, and *Cytherellina*. The entire Crustacean fauna consists of 27 genera and 78 species; the Upper Llandovery transmits to it 7 genera and 14 species; 74 of the 78 species occur in the Wenlock Limestone; and the 4 species wanting are *Homalonotus cylindricus*, *Ceratiocaris ludensis*, *Primitia excavata*, and *P. lenticularis*.

The poverty of the Crustacea in the Tarannon and Denbighshire Grits might be expected from the lithological characters of the rocks; only 8 of the 78 occur in the former, and 5 in the latter horizon. North Wales has yielded but 5 genera and 11 species, and South Wales 9 genera and 14 species; only 3 species occur in Scotland—*Turrilepas Wrightianus*, *Beyrichia Klædeni*, and *Phacops Stokesii*. Eight species occur in Ireland—*Calymene Blumenbachii*, var. *Allportiana*, *Cheirurus bimucronatus*, *Encrinurus punctatus*, *E. variolaris*, *Phacops caudatus*, *P. nudus*, *P. Stokesii*, and *Proëtus latifrons*. The order Merostomata makes its first appearance in the Wenlock Limestone through *Eurypterus punctatus*, *Hemiaspis horridus*, and *Pterygotus problematicus*.

Of the whole group of Crustacea, 13 genera and 18 species pass up to the Lower Ludlow, whose Crustacean fauna numbers 18 genera and 47 species.

Polyzoa.—Of the 11 known genera that occur, 6 are new, or first appear in the Wenlock; these are *Cellepora*, *Ceriopora*, *Diastopora*, *Discopora*, *Escharina*, and *Polypora*. No less than 24 species are known in the shales and limestones; none have occurred in the Tarannon Shales, Denbighshire Grits, or anywhere in North Wales or Scotland.

Most of the Palæozoic genera belong to the order Gymnolæmata, suborder Cyclostomata. We know of no Palæozoic genera extending into the Secondary Period, where this class attains its maximum development.

Brachiopoda.—In the Wenlock as in the Caradoc rocks, the Brachiopoda greatly predominate over most of the other groups—22 genera and 101 species occur, being an increase of 7 new genera, namely, *Athyris*, *Cyrtia*, *Eichwaldia*, *Nucleospira*, *Obolus*, *Orbiculoidea*, and *Retzia*. Twenty-one genera and 96 of the 101 species belong to the Upper Wenlock or Wenlock Limestone and shale; all the 22 genera known are also represented in the same horizon. The Woolhope beds yield 17 genera and 56 species, every Woolhope shell being also Wenlock. *Orthis Mullockensis*, or its variety *O. reversa*, may stand alone as a Woolhope species, but every other form is equally Wenlock.

The following species have the longest range in the Wenlock rocks both in time and space:—

Atrypa reticularis.	**Rhynchonella nucula.**
Chonetes striatella.	**Spirifera elevata.**
Crania implicata.	—— exporrecta.
Leptæna transversalis.	Strophomena pecten.
Meristella tumida.	—— rhomboidalis.
Orthis elegantula.	

All those named have appeared before in the Llandovery or Caradoc, and all pass to the Ludlow; but their universality through the Wenlock renders them conspicuous or long-lived (though not perhaps the best) witnesses in determining the age of any particular horizon through the Wenlock deposits.

Out of the 101 known Wenlock Brachiopoda, 56 species had not previously occurred in any earlier formation, but first appeared in the Woolhope and Wenlock limestone; these newly introduced Wenlock forms represent 20 genera. We deem it important to name them, with the numbers of the species in each; they are :—

	Species.		Species.
Athyris . . .	3	Obolus . . .	3
Atrypa . . .	2	Orbiculoidea . .	2
Crania . . .	3	Orthis . . .	6
Cyrtia . . .	1	Pentamerus . .	3
Discina . . .	4	Retzia . . .	2
Eichwaldia . .	1	Rhynchonella .	4
Leptæna . .	2	Siphonotreta . .	1
Lingula . .	2	Spirifera . .	3
Meristella . .	4	Strophomena . .	8
Nucleospira . .	1	Triplesia . .	1

Out of so large a fauna as 101 species, 96 of which occur in one division (the Wenlock Limestone and Shale), we should expect to find a large proportion absolutely restricted to that horizon. Of such restricted species in the true Wenlock rocks, we have 24 or 25 per cent. None of the following species occur in any other formation; and they may therefore be accepted as definitely typical Wenlock species—*Atrypa Barrandii, Crania Grayii, C. Sedgwickii, C. Silurience, Cyrtia nasuta, Leptæna segmentum, Meristella nitida, Nucleospira pisum, Obolus Davidsoni, Orbiculoidea Becketiana, Orthis æquivalis, O. basalis, O. Lewisii, O. Hughesii, Retzia Salteri, Siphonotreta Anglica, Spirifera sulcata, Strophomena Dayi, S. Fletcheri, S. Hendersoni, S. Orbignyi, S. Walmstedti, S. Waltoni,* and *Triplesia MacCoyana.*

The Wenlock Brachiopoda of Scotland comprise 11 genera and 20 species, most of them belonging to the long-range species, the more restricted being *Meristella Maclareni, Nucleospira pisum, Orthis Lewisii, O. Wenlockensis, O. polygramma,* and *Strophomena Hendersoni.*

The Irish Wenlocks contain 14 genera and 31 species; the most important are *Obolus Davidsoni, Pentamerus undatus, Rhynchonella Beltiana, R. deflexa, Orthis rustica, Spirifera bijugosa,* and *Strophomena Dayi.* The genera numerically rich in species are *Orthis* (16 species), *Rhynchonella* (10), *Spirifera* (8), *Strophomena* (16), *Penta-*

merus (6), *Meristella* (5), and *Atrypa* (5). The rarer genera are but feebly represented.

Pelecypoda.—Out of the 16 genera and 44 species of bivalve shells ranging through the Wenlock rocks, the Limestone or upper division yields 43 species, the *one absent* or uncertain form being, doubtfully, *Conocardium aliforme*. The Wenlock rocks of North Wales furnish 8 genera and 14 species, *Pterinæa*, *Cardiola*, and *Cucullella* being the chief. *Pterinæa* has yielded 6 species, *Cardiola* 3, and *Cucullella* 3; other genera (*Avicula*, *Arca*, &c.), only one or two species each.

Of the 3 Irish genera the 6 species are—*Pterinæa lineata*, *P. planulata*, *P. retroflexa*, *Cardiola fibrosa*, and *C. interrupta*, with *Goniophora cymbæformis*; none are confined to the Irish beds.

Gasteropoda.—Looking at the splendid series of Cœlenterata, Echinodermata, Crustacea, and Brachiopoda in the Wenlock series, the distribution and ranges of which we have analysed, we should have expected this class to have been more largely represented, especially as during the Caradoc and Upper Llandovery periods *a larger molluscan fauna* existed, although apparently the nature of the sea-bed was not so favourable as that of the more calcareous and argillaceous condition of the Wenlock, in which the great mass of the fauna occurs. All the genera belong to the Prosobranchiata and division Holostomata. Ireland yields *Murchisonia articulata*, *M. Lloydii*, *Euomphalus alatus*, *Cyclonema corallii*, and *Acroculia haliotis*. Four genera and 6 species range from the Upper Llandovery; these are *Euomphalus alatus*, *E. furcatus*, *E. sculptus*, *Holopella obsoleta*, *Loxonema sinuosa*, and *Murchisonia articulata*; *Euomphalus alatus* and *E. sculptus* occur in the Caradoc. At present we know of no species in the Silurian rocks other than those in the division Holostomata. *Eunema* is the only new genus recorded in this formation.

Pteropoda.—Only 3 species, *Conularia Sowerbyii*, *Theca anceps*, and *T. Forbesii*, have as yet appeared in the Wenlock group. *Theca Forbesii* occurs in the Denbighshire Grits and Wenlock Limestone, and passes upwards to the Upper Ludlow. *T. anceps* is here Wenlock only, but is a Caradoc species also. *Conularia Sowerbyi* first appeared in the Caradoc, and, with the exception of the Upper Llandovery, is present in all horizons up to the close of the Upper Ludlow; it also occurs in the Scotch beds. *Conularia* is the only form of Thecosomatous Pteropod that transgresses the Silurian rocks. The genus occurs in the Devonian and Carboniferous rocks.

Heteropoda.—This pelagic order is represented in the Wenlock beds through *Ecculiomphalus lævis* and seven species of *Bellerophon*; but no species is confined to, or specifically characteristic of, the Wenlock beds. *Ecculiomphalus lævis*, *Bellerophon trilobatus*, and *B. carinatus* range into the Upper Ludlow beds.

B. dilatatus is the only form known in Ireland; and Scotland yields none.

Cephalopoda.—Five genera and 30 species of the order Tetrabranchiata illustrate the Nautilidæ and Orthoceratidæ; all but 3

species are represented in the Wenlock Limestone and Shale; these are Woolhope species (*Actinoceras baccatum*, *Lituites cornu-arietis*, and *Orthoceras conicum*). *Actinoceras baccatum* is essentially Woolhope, and the only one known in the Woolhope beds.

The only three Irish species are *Orthoceras* (*Creseis*) *primævum*, *O. subundulatum*, and *O. tenuicinctum*; and the Scotch species are *O. Maclareni*, *O. subundulatum*, and *O. tenuicinctum*. Eleven species pass to the Lower Ludlow; and the only two known (*Lituites giganteus* and *Orthoceras angulatum*) also pass to the Aymestry Limestone; 3 genera and 8 species range to the Upper Ludlow; thus only 4 genera and 9 species out of the 30 are really Llandovery, or species which passed up from the Llandovery and Caradoc.

Fish.—The oldest fish-remains occur in the Lower Ludlow, *Scaphaspis ludensis* being the earliest species on record.

Foreign Equivalents of the Wenlock Rocks.

(Niagara Group of America.)

In America.—The upper part of the Niagara group is the equivalent in time of our *Wenlock shales and limestones*. The limestones especially occupy a vast area over and through the Mississippi basin. Along the Appalachian mountains and southwards, the rocks belong mostly to the "shales," as in Britain. The underlying Clinton beds of the Upper Llandovery age are connected through numerous fossils, both areas containing many species common to the same horizon in the British Islands. These Niagara or Wenlock shales also occupy extensive areas in Arctic and British America, notably so in Hudson's Bay; the Actinozoa and Crinoida having, as in Britain, been the chief agents in producing the limestones.

The Niagara limestone of the Arctic regions in America is known to extend to the parallel of 72° and 76°, to the shores of Welling and Barrow Straits. Its ancient sea, however, extended further, and deposited its rich assemblage of life within 7° of the Pole; both sides of Smith's Sound, on the west side of Greenland, as far north as 83°, being composed of the Niagara or Wenlock rocks, and containing a rich fauna undistinguishable from that of England, Wales, Scotland, and Scandinavia.[1]

The Clinton Limestones are often magnesian, a condition unknown in this country or in Scandinavia.

At the Niagara Falls this limestone is about 90 feet thick, overlying 80 feet of shale. The cutting back of the bed of the River Niagara is due to the removal of the underlying shales, thus undermining the limestone. In Eastern Canada, south of the St. Lawrence, it is also present. In Ohio, Indiana, and Illinois, this and the over-

[1] Captain Feilden (of the ship *Alert*), naturalist to the late Polar Expedition, obtained and brought home a very characteristic series of Wenlock and carboniferous fossils (*vide* Q. J. G. S., vol. xxxiv. pp. 568-639, for descriptions of the species by R. Etheridge).

lying corniferous rock, "cliff limestone," is about 100 feet in thickness, and constitutes the bluffs of the river valleys, the strata being in thick beds, and nearly horizontal.

Like our own series, the American limestones are often nodular and concretionary, showing similarity of condition during deposition over so extensive an area. Even if this condition was subsequently superinduced, it nevertheless shows original similarity of condition, or a physical structure common to the whole series when deposited.

The original connection of the British Islands, Scandinavia, and Western Europe, with the American continent, is through no group so clearly seen as in the Wenlock or Niagara series. The organic remains of the two areas are extensively the same, numerous species being identical. That it was along the once continuous but now dismembered line of coast from the north of Scotland, Norway, Spitzbergen, Greenland, to Ohio or Indiana, &c., &c., that this ancient diffusion of life took place, is highly probable—indeed, scarcely problematical. Another and now deeply seated or depressed continent (or portion of one) which exists beneath the Atlantic, between Spain and Eastern America, may probably once have occupied that region. Certain it is, however, that the Palæozoic rocks of Britain and Western Europe did not then (and neither do they now) terminate along their present line of exposed coast, or longitude 10° W. The present Atlantic may, and probably does, roll over every subdivision of the Palæozoic rocks, as varied in structure and life-contents as those exposed on both sides of its boundary. Want of continuity is only *apparent*, and no student can observe the wonderful promontory of St. David's, the western prolongation of Cornwall, the physical structure of Wales and Cumberland, the lost and detached members of the western coast and Highlands of Scotland, from Arran to Cape Wrath, and the intermediate but isolated position of Ireland, and its abrupt, varied, and incomplete west coast, without feeling assured that extension and geological continuity were once and are now a reality in the Atlantic basin, and that numerous oscillations and changes between the relative positions of land and sea (coast line and sea level) have taken place. Without such varying coast line, the fauna of the shores of those regions in the sea where ordinary life exists, could not have lived, or migrated, or have been developed. Such continuous coast lines and land in the Silurian, Devonian, and Carboniferous epochs did exist (intermittently, perhaps) over much of the Atlantic basin and Northern Hemisphere from lat. 30° to the Pole.

Identity of British and American Silurian Life.—The fossil evidence alone, in the Wenlock group of rocks, shows continuity along some shore line, or continent, whose life-history was long enough to unite the now separated continents of America and Europe. The same corals, Crustacea, Brachiopoda, and Echinodermata, now found fossil in both areas, then existed, possessing the same function and having the same habits, and none of them of very deep-sea life—

Halysites catenalatus, Hypanthocrinus decorus, Orthis elegantula, Pentamerus oblongus, Atrypa reticularis, Homalonotus delphinocephalus, Calymene Blumenbachii, Illænus Barriensis, and many others; the commonest British fossils occur in the Niagara and Wenlock rocks and connect the two now distant but once connected areas. No less than 30 species are common to the two countries.

The Arctic (American area), Wenlock, and Niagara fossils are—

Halysites catenulatus, Favosites Gothlandica, Stromatopora concentrica, Heliolites, Syringopora, Favistella, Calymene, Asaphus, Leperditia Balthica, Orthis elegantula, and *Atrypa reticularis*.

These are our species and Scandinavian also, some occurring as far north as lat. 83°.

The Lower Helderberg Period.—This division in America corresponds to the upper part of our Wenlock group, probably a portion of the Lower Ludlow. The following species connect the rocks of the two countries:—*Strophomena rugosa, Atrypa reticularis*, and *Pentamerus galeatus*. Professor Hall notices a number of other species closely allied to our British and European forms, but we believe them to be distinct.

Arctic America.—The Upper Silurian rocks of this region in America, contain a suite of fossils essentially European, 7 or 8 being identical, and those we should expect to find from the abundance of the species everywhere. The ubiquitous *Halysites catenulatus, Favosites Gothlandica, Stromatopora concentrica, Orthis elegantula*, and *Atrypa reticularis*, range over the whole northern region, here and there having species of equal importance, as bearing upon the distribution of life and land during the Upper Silurian period.[1]

Scandinavia.—In Scandinavia, the limestones and sandstones of Gothland represent the Wenlock series of England and Wales, and the Niagara epoch and Lower Helderberg period of America. The community of fossils and general species also clearly determines their correlation with ours.

Species common to Scandinavia and Britain.—The following species, amongst others, are common to the Wenlock rocks of Britain and the Scandinavian peninsula.

ACTINOZOA.—*Halysites catenulatus, Heliolites pyriformis*, and *Stromatopora concentrica*.

CRINOIDEA.—*Eucalyptocrinus decorus*.

BRACHIOPODA.—*Orthis elegantula, O. hybrida, O. biloba, Leptæna transversalis, Strophomena rhomboidalis, Spirifera crispa, S. radiata, S. sulcata, Atrypa reticularis, Meristella nitida, Retzia cuneata, Spirifera plicatella*, and the Trilobite, *Calymene Blumenbachii*.

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[1] See Q. J. G. S. vol. xxxiv., pp. 568–639, Etheridge. Palæontology of the coasts of the Arctic lands visited by the British Expedition under Captain Sir G. Nares, R.N., &c.

CHAPTER XVI.

THE LUDLOW GROUP.

LUDLOW ROCKS—
Upper Ludlow rock = Upper *Pentamerus limestone.* (America.)
Aymestry limestone = *Pentamerus Knightii limestone.*
Lower Ludlow shales = Waterlime group. (America.)
Couche à *Harpes venulosus*, D'Herbray, Loire Inf.
Etage F. 1, 2, Calcaire Moyen, Barrande. (Bohemia.)
Upper Pentamerus limestone. } North America.
Lower Helderberg division. }

Range of the Ludlow Rocks.—The town of Ludlow gives the name to this group of strata, which in reality cannot well be separated from the preceding Wenlock series. The beds are finely exhibited at Ludlow, on the banks of the river Teme, which has worn its course through these strata. The lower and middle divisions are best seen in the escarpment to the south-west of the town, or along the ridge of the Wenlock promontory, or between that range and the old red sandstone of Corve Dale. In the Begum and Clyro Hills, from Kington towards the south-west, the Ludlow rocks are also typically developed on the banks of the Wye near Builth.

Fauna of the Ludlow Rocks.—The fauna is composed of almost every order, but the Crustacea, Brachiopoda, and Pelecypoda are most abundant. The Crustacea number 29 genera and 97 species; the Brachiopoda, 13 genera and 48 species; the Pelecypoda, 17 genera and 70 species; the Cephalopoda are represented by 6 genera and 37 species; the Gasteropoda by 9 genera and 33 species; the Echinodermata by 12 genera and 17 species; and the Actinozoa (corals) by 12 genera and 17 species. The class *Fishes* (which here first appear) has yielded 10 genera and 14 species.

The whole fauna of the *Ludlow series, i.e.*, the *Lower Ludlow, Aymestry limestone,* and *Upper Ludlow rocks,* numbers 137 genera and 392 species; or taken separately, they stand as follows:—

		Genera.	Species.
Ludlow group.	Upper Ludlow . .	102	258
	Aymestry limestone .	53	84
	Lower Ludlow . .	98	222

Thirty-nine genera and 66 species occur in the passage beds (Ledbury shales and Downton beds), but 12 genera and 20 species pass to the Devonian rocks above. The intimate faunal connection of the Ludlow group with the Wenlock is clear, when we know that out of the 98 genera and 222 Lower Ludlow species, 73 of the former and 130 of the latter passed from the Wenlock to the Ludlow sea. The following is the geographical distribution of the Ludlow rocks through eight chief areas:—

	Genera.	Species.
South Wales	70	163
North Wales	13	19
Westmoreland	57	127
Shropshire	88	187
Worcestershire	70	121
Herefordshire	62	114
Scotland	39	63
Ireland	20	32

With the exception of a small area south of Newtown, in Montgomeryshire, no true Ludlow rocks are known in North Wales; less than 20 species have been recorded there.

Lower Ludlow.

Lower Ludlow Series.—This division of the Upper Silurian in the Ludlow district in Shropshire, Woolhope, and Malvern areas in Herefordshire, Radnor Forest, and part of Montgomery, is chiefly composed of dark, greenish-grey, sandy shales, with calcareous, lenticular, nodular concretions.

Physical Condition.—The lower strata are chiefly argillaceous, and occur in large spheroidal masses, which exfoliate with exposure, breaking up into innumerable small fragments. Dark calcareous nodules, having organic remains as a nucleus, frequently occur throughout. *Calymene Blumenbachii*, *Phacops longicaudatus*, and *P. caudatus*, are common trilobites in these nodules. In structure the beds are usually soft, decomposing readily upon exposure to the air; locally these shales are termed "*mudstones*." The shales underlie the Aymestry limestone, which usually rests upon a kind of impure clay, provincially called "Fuller's earth." The Ludlow series must be regarded as an upward continuation or extension of the Wenlock, being intimately connected, especially through the fauna of the Wenlock shales.

The higher beds in this group are earthy and slightly calcareous flagstones, and have yielded at Leintwardine near Ludlow a remarkable series of *Asteriadæ* (star-fishes) and Crustacea (Trilobita). Amongst the former are species of *Protaster*, *P. Miltoni*, *P. leptosoma*, and *P. Sedgwickii*; *Palæocoma Marstoni* and *P. Colvini*; the last two species are allied to the living genus Palmipes. *Palæodiscus ferox*, *Palæaster* (2 species), and *Palæasterina primæva*; some 12 or 14 species are known to have close affinities with modern types. None of these species occur in the Shropshire or Herefordshire areas, or where the typical *Upper Ludlow* is developed.[1] Four species of star-fishes occur in and are confined to the Kendal and Kirkby moor-flag group, or Upper Ludlow of Westmoreland. They are *Palæaster hirundo*, *P. Ruthveni*, *Palæasterina primæva*, and *Protaster Sedgwickii*, associated with an equally local and distinctive fauna.

Lithologically, also, the beds differ entirely from those of the typical area, being red and dark coloured, hard, calcareous flagstones

[1] Ludlow, Ledbury, Malvern, Abberley, Usk, May Hill, &c.

and grits, with coarse micaceous slates and tilestones. The slabs in places are crowded with fossils. About 100 species are known in the Westmoreland Ludlow beds, and 200 in the Shropshire and Herefordshire series. No less than 6 genera and 22 species of Cephalopoda (chiefly Orthoceratidæ) range through the Upper Ludlow beds; they are *Orthoceras* 17 species, *Phragmoceras* 2, *Lituites* 1, *Ascoceras* 1, and *Tretoceras* 1 species. The Orthocerata confined to the Upper Ludlow are the 8 following—*Orthoceras baculiferum*, *O. gregarium*, *O. ibex*, *O. laqueatum*, *O. imbricatum*, *O. per-elegans*, *O. striato-punctatum*, *O. tenuicinctum*, and *O. textile*.

The shale of the Lower Ludlow is a prominent feature in the escarpments which range through Shropshire, especially its western part, and on to Radnor Forest, and parts of Montgomeryshire around Welshpool. From the high ground and valley west of Kington to Mynydd Epynt in Brecknockshire, this lower shaley division in the typical Malvern tract (Woolhope, Malvern, &c.) is 750 feet in thickness.

Numerical Estimate of Fauna.—The Lower Ludlow is characterised by its many straight and curved Cephalopoda, *Orthoceras*, *Phragmoceras*, and *Lituites*, &c. No less than 24 species of the first-named genus (*Orthoceras*) occur in the whole Ludlow series, 15 of which are in *Lower* Ludlow, with 6 species of *Phragmoceras* and 3 species of *Lituites*.

The Crustacea number 47 species, the Brachiopoda 38, Pelecypoda 34, Gasteropoda 15, Actinozoa 17, Echinodermata 19. The orders *Merostomata* and *Eurypterida* may be said to really *commence* here; 14 out of the 20 species are Lower Ludlow, 2 species only being known in the Wenlock, viz., *Eurypterus punctatus* and *Hemiaspis horridus*.

Scaphaspis Ludensis is the first and only known fish in the Lower Ludlow, and is also the first recorded remains of the class, the remaining 7 genera and 11 species being all Upper Ludlow.

Species Characteristic of the Lower Ludlow Rocks.—The following species are characteristic of the Lower Ludlow rocks:—

Syringopora serpens, *Omphyma turbinata*, *Echinocystites pomum*, *Palæocoma Colrini*, *Palæodiscus ferox*, *Protaster Miltoni*, *Palæaster hirudo*, *Dictyocaris Ramsayi*, *Deiphon Forbesii*, *Encrinurus variolaris*, *Hemiaspis speratus*, *Lichas anglicus*, *Phacops longicaudatus*, *Proetus latifrons*, *Homalonotus*, *Lingula lata*, *Pentamerus galeatus*, *Rhynchonella navicula*, *Strophomena euglypha*, *Pterinea planulata*, *Cardiola fibrosa*, *Cucullella Cawdori*. *Orthonata affinis*, *O. semisulcata*, *Euomphalus centrifugus*, *Loxonema sinuosa*, *Murchisonia Lloydii*, *Bellerophon expansus*, *Lituites giganteus*, *Orthoceras annulatum*, *O. filosum*, *Scaphaspis ludensis*. Localities—Woolhope, Dormington, Onibury, Mocktree, Vinnal Hill, May Hill, Malvern, and Usk; indeed, every district where developed.

Aymestry Limestone (*Ludlow Limestone*).

This is not a persistent band of limestone over an extended area, but a lenticularly developed bed of impure limestone between the Lower and Upper Ludlow series, capable of being more or less traced wherever

the Ludlow series are present. The calcareous condition of the Aymestry or Ludlow Limestone is due mainly to the presence of one or two species of shells, notably the *Pentamerus Knightii* (Plate VII. fig 3). This rock appears to be an accidental deposit in the middle part of the Ludlow group, extending over a given area mainly in the Ludlow promontory at Aymestry, &c., and west of Wenlock Edge it is also well exposed at many other places; Sedgley in Staffordshire, Woolhope, west of the Malvern Hills, Abberley, May Hills. At Aymestry this limestone occupies both sides of the river Lugg, and is extremely fossiliferous, the type-shell *Pentamerus Knightii* occurring in thousands. In the Woolhope Valley the physical features of the Aymestry rock are the same as those of the Ludlow promontory. At Woolhope it forms the crest of the external and encircling edge, and surmounts the hills of Seager, Marden, and Blackbury. The Aymestry Limestone also occupies the central portion of the Ludlow rocks on the western slopes of the Malvern Hills, and along the flanks and summit of the Abberley range. The thickness varies from 15 to 40 feet, assuming various lithological conditions, depending much upon the local distribution of its fossil contents. It is a dark-grey, semi-crystalline limestone in one place, an argillaceous or earthy limestone in another; when containing little lime, it assumes the character of a calcareous flagstone.

It is a marked feature between the Lower and Upper Ludlow beds when thus exposed, and forms escarpments or cliffy outcrops between the two; it is also extensively jointed, and in places crowded with its characteristic fossils. Many forms, again, are common to it and the Wenlock, the repetition of conditions seeming to favour a community of species between two distant and widely-separated formations.

Palæontology of the Aymestry Limestone.

The fauna of the Aymestry Limestone comprises 53 genera and 84 species, 52 of which are common to the Wenlock limestone and shale. Six species are, so far as we know, *peculiar* to the Aymestry, viz., *Eurypterus scorpoides, Ceratiocaris inornatus, Orthis canaliculata, Cyclonema quadristriata, Murchisonia cingulata*, and *Pleurotomaria undata*. The remaining 78 species are distributed through the Ludlow group. The following are the most characteristic fossils of the Aymestry limestone :—

ACTINOZOA.—*Chonophyllum perfoliatum, Cyathaxonia Siluriensis, Cyathophyllum truncatum, Heliolites interstinctus.*

ECHINODERMATA.—*Palæasternia primæva, Protaster Sedgwickii.*

ANNELIDA.—*Serpulites longissimus, Tentaculites ornatus.*

CRUSTACEA. — *Calymene Blumenbachii, Homalonotus delphinocephalus, Phacops caudatus.*

HYDROZOA.—*Ptilodictya lanceolota.*

BRACHIOPODA.—*Atrypa reticularis, Chonetes striatella, Lingula Lewisii, L. lata, Meristella didyma, Pentamerus Knightii, Rhynchonella navicula, R. Stricklandi, R. Wilsoni, Strophomena Euglypha.*

PELECYPODA.—*Pterinæa hians, P. retroflexa, Cardiola striata, Grammysia cingulata, Orthonota semirulcata.*
GASTEROPODA.—*Cyclonema undifera, Euomphalus funatus, Loxonema sinuosa.*
HETEROPODA.—*Bellerophon trilobatus.*
CEPHALOPODA.—*Lituites giganteus, Orthoceras tenuiannulatum.*

Remembering that the entire fauna of the Ludlow group numbers 392 species, the above 33 characteristic forms are by no means a large percentage. The occurrences in each division are—In the Lower Ludlow, 222; Aymestry limestone, 84; and the Upper Ludlow, 258 species. This large number in the upper division arises probably from the crowding and abundance of life at the close of the Silurian system, or from those changes between sea and land which must then have taken place, the shallowing of the Silurian sea-bed producing extended shallow-water conditions; and, finally, within our own area, causing either migration or slow destruction of the marine fauna. The Downton and Ledbury shales, with their scanty fauna, closed the Silurian series, no invertebrate species passing into the succeeding (although conformable) *Old Red Sandstone* in the Welsh or Silurian area.

Upper Ludlow.

Upper Ludlow Rock.—Of the three subdivisions of the Ludlow group this is the most diversified; it is the highest part of the Ludlow proper. The Downton Sandstones, Tile Stones, and Ledbury Shales (once all united under the name "Tile Stone beds") are the passage or transition series into the succeeding and conformable Old Red Sandstone of the Silurian area, and contain a peculiar group of fossils.

Physical Structure and Distribution.—The physical structure of the beds, or their lithological character, differs much from that of the subjacent series.

The rocks are grey, calcareo-argillaceous and micaceous thin-bedded shales and flagstones; but these characters vary in different localities, where deposited under different conditions. The Ludlow-rock group of Westmoreland has no lithological representative whatever of the typical Ludlow of Wales, Herefordshire, and Shropshire, &c.; nevertheless, the organic remains are the same, and the beds possess the same facies of organic remains.

The Upper Ludlow maintains its character and general features throughout its distribution and range, and distinctively so through Herefordshire, Shropshire, Radnor, Brecknock, Carmarthenshire, and Pembrokeshire, everywhere exhibiting the same succession of beds and characteristic fossils.

Range and Fauna of the Upper Ludlow.—In Carmarthenshire the junction of the Ludlow rocks with the overlying and succeeding Old Red Sandstone is well exhibited between Trecastle and Llandovery, where the Downton beds of Horeb Chapel are full of mollusca, especially the following characteristic species:—

Platyschisma helicites, P. Williamsoni, Bellerophon carniatus, Holopella obsoleta, H. greyaria, H. conica, Cucullella antiqua, Chonetes striatella, and *Orthoceras tracheale,* which everywhere abound on this horizon and equally characterise the Ludlow rocks of Westmoreland.

In the Woolhope Valley, around the whole elliptical dome, the succession of the Upper Ludlow in the Old Red Sandstone is complete, and the beds teem with the ordinary fossils, especially—

Chonetes lata (striatella), Lingula cornea, Orthis elegantula, Atrypa reticularis, Rhynchonella navicula, Strophomena euglypha, Serpulites longissimus, Trachyderma squamosa, Pterinæa, Grammysia, Orthonota angulifera, Holopella gregaria, and one or two forms of *Orthoceratites.* These species occur more or less abundantly in most sections.

At Hagley Park, east of Hereford, the uppermost Ludlow beds are seen beneath the red marls and clays of the Old Red Sandstone. The Ludlow Bone-bed, containing fish-remains, is here exposed, and above this in sandy beds occur the peculiar seed-vessels termed *Pachytheca.* This bone-bed occurs at Brookhill and Hales End, May Hill and Huntly Hill, everywhere charged with fish-remains, and frequently also with the Lower Ludlow shells.

Near Kington this Ludlow bone-bed occurs, and is overlain by strata containing *Chonetes lata (striatella), Orthonota amygdalina,* succeeded by other beds containing *Platyschisma helicites* and *Lingula cornea, Phragmoceras nautileum, and Tretoceras semipartitum.*

Palæontology of the Upper Ludlow Rocks.

Fifty-six species of Pelecypoda and 58 species of Crustacea are recorded as also occurring, with 15 species of Brachiopoda and 20 species of Gasteropoda. Fishes here make their first truly recognisable appearance in time, no less than 10 genera and 14 species occurring. They are—

Auchenaspis Salteri, Cephalaspis ornatus, C. Murchisoni, Onchus Murchisoni, O. tenuistriatus, Plectrodus mirabilis, P. pleiopristis, Pteraspis Banksii, P. truncatus, Scaphodus Ludensis, Sphagodus pristodontus, Thelodus parvidens, Thyestes verrucosus.

The Crustacea are remarkable for the abundance and number of the species of the order Merostomata and sub-order Eurypteridæ, which culminated in the Ludlow group. Twenty species are distributed in the 4 genera *Hemiaspis, Pterygotus, Slimonia,* and *Stylonurus.* The order Phyllopoda, through *Ceratiocaris,* 7 species; *Dictyocaris,* 1 species; *Entomis,* 3 species; and a few other minute forms; in all 13 species highly characterise the Upper Ludlow rocks. The Pelecypoda of the *Upper Ludlow* greatly preponderates over the *Lower,* comprising double the number of species (56). The group Pteria (monomyaria) contains 12, and the Dimyaria 44 species.

The following genera have the greatest specific value:—*Anodon-*

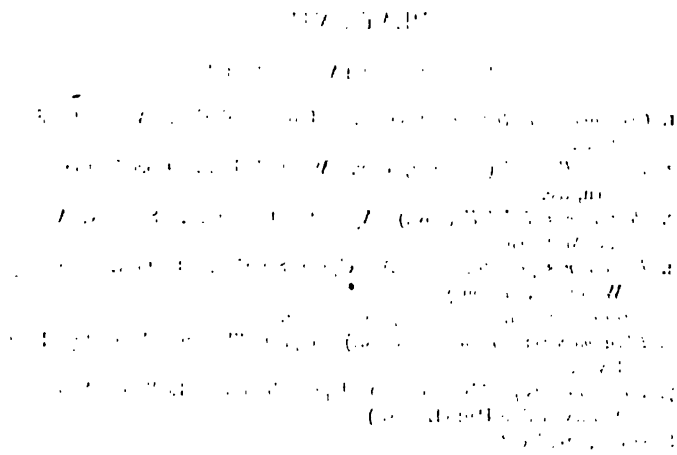


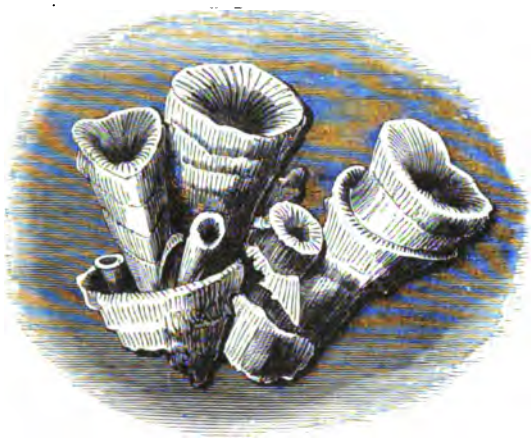
PLATE VII.

UPPER SILURIAN FOSSILS.

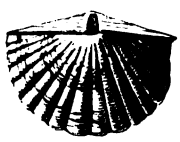
1. *Cyathophyllum truncatum* (Lim.) Upper Silurian. Wenlock Limestone.
2. *Discina Forbesii* (*Orbicula*) Dav. Wenlock beds. Dormington, Malvern, &c.
3. *Pentamerus Knightii* (Sow.) Aymestry Limestone. Sedgley, Aymestry, Malvern.
4. *Pentamerus galeatus* (Dalm.) Upper Silurian. Ludlow, Aymestry, Woolhope, Ledbury.
5. *Lituites cornu-arietis* (Sow.) Presteign.
6. *Phragmoceras ventricosum* (Sow.) Upper Silurian. Aymestry, Dudley, &c.
7. *Phragmoceras pyriforme* (Sow.) Upper Silurian Ledbury, Aymestry, Leintwardine Hill (Ludlow).
8. *Orthis*, sp., loc. ?.

PLATE VII.

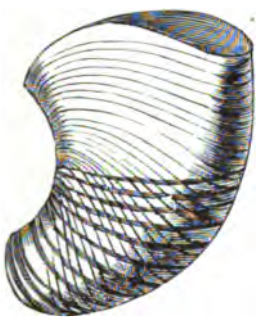
UPPER SILURIAN FOSSILS.



1

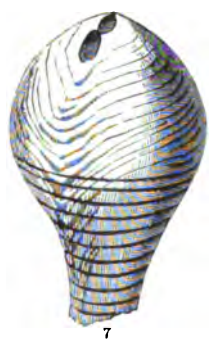


8



6

5



7

3

2

4

topsis, 6 species; *Cucullella* 3, *Grammysia* 4, *Modiolopsis* 5, and *Orthonota* 14. This last genus (*Orthonota*) is one of the most important in the Upper Silurian rocks; it numbers no less than 24 species, ranging from the Upper Llandovery or May Hill group to the Downton sandstone. *Modiolopsis* must be regarded as of equal stratigraphical value.

The Gasteropoda through *Cyclonema*, *Euomphalus*, *Holopella*, *Murchisonia*, and *Platyschisma* retain their importance as Upper Ludlow or Upper Silurian genera, unitedly constituting 16 species, while the entire Ludlow group yields 24 species.

The Pteropoda and Heteropoda almost attain their maximum through 4 genera, *Conularia*, *Ecculiomphalus*, *Theca*, and *Bellerophon*, which unitedly distribute 9 species. The Cephalopoda through *Orthoceras*, with 17 species, *Lituites*, *Phragmites*, and *Tretoceras*, 1 each (in all 20 species), are characteristic, as none pass to the succeeding Old Red Sandstone. It is chiefly in the upper beds that the fossils are most crowded and best preserved, and especially so in the passage series. The following species are the most abundant in the uppermost Ludlow :—

Discina rugata, *Orthis elegantula* var. *orbicularis*, *O. lunata*, *Rhynchonella nucula*, *Chonetes striatella*, *Orthonota amygdalina*, *Goniophora cymbæformis*, *Pterinæa lineatula*, *P. retroflexa*, *Cyclonema coralii*, *Serpulites longissimus*, *Beyrichia Wilckensiana*, *Alveolites fibrosus* (encrusting Gasteropoda), *Cornulites serpularius*, and *Tentaculites*.

Ludlow Bone-Bed.—This well-known band, composed of the remains of fishes, crustacea, plants (seeds of Lycopodiacea), and a few mollusca, caps the uppermost beds of the Ludlow series. It is typically developed at Ludlow, and found at Stoke Edith, and all round the Woolhope ellipse, at Hales End near Malvern, May Hill, Huntly Hill, Pyrton Passage, Bradnor Hill near Kington, and, generally, where the junction of the Downton sandstones with the Upper Ludlow is observed. The fossil contents of this deposit comprise the following species :—

Fauna of the Ludlow Bone-Bed.—*Platyschisma helicites*, *Modiolopsis*, *Lingula cornea*, *Holopella concinna*, *Discina rugata*, *Orthis elegantula*, tail spines of crustacea, fragments of large Pterygoti, fish defences (*Ichthyodorulites*), *Onchus Murchisoni*, *O. tenuistriatus* (probably tail spines (telsons) of crustacea), skin and scutes of *Sphagodus pristodontus*, jaws of *Plectrodus mirabilis*, *P. pustuliformis*, and *Pteraspis*; also the *Lycopodiaceous* plant (or alga) *Pachytheca sphærica*. These and many more constitute or make up this (in places) densely packed organic bed.

This chief or lower bone-bed is, however, overlain by other strata containing similar remains, but with an additional facies and of different mineral characters. These are the true passage-beds between the Silurian and Devonian or Old Red Sandstone :—

Tile Stones.

Tilestones, Passage-beds, or
Ledbury Shales,
Downton Sandstones,
Bone Bed.
Étage H, 1, 2, 3, Schistes Culminants.
Étage G, 1, 2, 3, Calcaire Supérieur avec Poissons. Bohemia.
Upper Pentamerus Limestone } Lower Helder- } America.
Delthyris-Shaly Limestone } berg Division }

Transition Beds, Downton Sandstone, and Ledbury Shales.—These occur a little above the Ludlow or Lower Bone-bed. In the Downton area they are a series of grey, red, and yellow, thin-bedded, micaceous, and marly sandstones. They constitute the commencement of the transition series, a group about 350 feet thick, lying between the Upper Ludlow proper and the base of the Old Red Sandstone, to which it is in many places closely related.

Platyschisma helicites clearly defines its place palæontologically. The Downton sandstone is crowded in places with fossils, fragments of carbonaceous matter, Lycopodiaceous seeds, *Lingula cornea*, *Orthonota*, and *Modiolopsis*, *Pteraspis Banksii*, *P. truncatus*, *Eurypterus linearis*, *Pterygotus gigas*, and *P. Banksii*, with Leperditiæ. These constitute the chief fauna, attaining its greatest development in the "Olive or Tin-Mill shales," some 300 feet above the place of *Platyschisma helicites*. The variegated and green and grey micaceous sandstones, containing *Cephalaspis Murchisoni* and *Lingula cornea*, between the Downton bed and the Olive shales, yield but few other fossils. About the middle of the Olive shales are thin pale-brown argillaceous bands, thickly studded with fossils, and about the middle of these beds occurs the Upper Bone-bed, with its many fish-remains, species of *Onchus Murchisoni*, *O. tenuistriatus*, and fragments of *Cephalaspis Murchisoni*, *C. ornatus*, and *Auchenaspis Salteri*. In the shales themselves near Onibury, and the Tin-mills near Downton, several species of Eurypterids also occur, viz., *Eurypterus pygmæus*, *E. megalops*, *E. accuminatus*, and *Pterygotus Banksii*, and *Lingula cornea*. Purple micaceous grits containing *Lingula cornea* (*Lingula cornea* grit) cap the olive shale at the Tin-mills, passing into flaggy, micaceous, unfossiliferous flagstones, which constitute the base of the Old Red Sandstone.

The Downton beds are widely distributed, occurring under different physical conditions and varying in thickness, in Shropshire, Worcestershire, Herefordshire, Gloucestershire, and Pembrokeshire, wherever the Upper Ludlow and lower part of the Old Red Sandstone are visible, or along the eastern frontier of the Silurian deposits.

The Ledbury Shales.—These beds consist of grey, red, and purple marls, shales, and sandstones of considerable thickness at Ledbury (west of the Malvern chain). They are clearly the Downton beds under a different lithological aspect, and probably part of its highest members, *Auchenaspis*, *Pteraspis*, *Onchus*, *Pterygotus*, *Cephalaspis*, and

Lingula cornea occurring as in the Tin-Mill and Downton section, and finally passing unconformably into the overlying red and grey marls and sandstones of the Lower Old Red Sandstone, containing *Cephalaspis* and *Pteraspis*, &c.

CHAPTER XVII.

PALÆONTOLOGY OF THE LUDLOW ROCKS.

As nearly as can be ascertained, the numerical value of the Ludlow fauna is 392 species, representing 137 genera. No true Ludlow rocks are known to occur in North Wales, excepting perhaps in a small part of Montgomeryshire, south-east of Newton. The Ludlow formation is zoologically allied to the Wenlock through 129 species. The 7 chief classes, or those most numerically represented, are the Actinozoa with 12 genera and 17 species, the Echinodermata 12 genera and 21 species, the Crustacea 29 genera and 97 species, the Brachiopoda 13 genera and 48 species, the Pelecypoda 17 genera and 71 species, the Gasteropoda 9 genera and 33 species, the Cephalopoda 6 genera and 37 species, and lastly the Vertebrata, which first appear through the Fishes, represented by 10 genera and 14 species, omitting the genus *Onchus*, the remains of which may be "telsons" or tail-spines of Crustacea. The comparatively small fauna of the Aymestry Limestone (53 genera and 84 species), although local, is a remarkable one, and clearly shows the nature of its accumulation. Mostly, it is a recurrent fauna from the Wenlock, 57 species being common to the two; these 57 represent 38 genera, clearly showing the rarity and paucity of species illustrating the genera, and the lenticular or accidental nature of the Aymestry Limestone between the Lower and Upper Ludlow beds. The classes that appear to be most fully represented are the Cœlenterata (Actinozoa), the Crustacea, Brachiopoda, Gasteropoda, and Cephalopoda. No fish-remains are known, although the two Ludlow series contain them. The feeble representation of the Ludlow rocks in North Wales, as before stated (only 19 species), by comparison with Westmoreland (127), demands critical examination into the physical rather than the palæontological aspect of the question; and this is still more prominently seen through the still larger fauna in South Wales and Shropshire, the former yielding 163 species, the latter 187; and further through the intermediate area occupied by Herefordshire (where 114 species are known) and Worcester (121). Could we but see and examine the continuity of the old Wenlock and Ludlow sea-bed and its deposits between Denbighshire, Westmoreland, and the South of Scotland, now under the St. George's Channel (or denuded away), we should doubtless find traces of the Lower Wenlock and Ludlow rocks, uniting

the two now disunited areas. We cannot doubt that this continuity once existed, though probably the rocks of the two areas were deposited under very different local conditions. Petrologically they essentially differ; but palæontologically or specifically in certain groups the agreement is close and decisive, omitting the largely represented Annulose or Crustacean orders Merostomata and Phyllopoda in the Ludlow rocks (45 species), which stand alone as a peculiar and local group; their presence therefore need not enter into calculation.[1] The great extension of the Wenlock promontory to Wellington, running parallel to the Dudley beds, and the overlap and cover of the Triassic rocks to the north on to the Mersey, Liverpool Bay, Lancaster and Morecambe Bays, go far to lead us to believe that the missing evidence of the agreement between the Ludlow of the two areas of Wales and Westmoreland, as well as the unsatisfactory correlation of the Denbighshire Grits and Tarannon Shales with the rocks of the Lake country, could be accounted for; since it must be admitted that much has yet to be done with these Lower Wenlock rocks of Denbighshire, Westmoreland, &c. The Kendal group (or Ludlow rocks) and the Ireleth Slates, which are the equivalents of the Wenlock of the south, can certainly be correlated palæontologically, dissimilar as they appear physically. The uppermost Scotch Silurians are exhibited only in three localities; to the south of Kirkcudbright and in the Pentland Hills both the Wenlock and Ludlow groups occur. The American series termed the Lower Helderberg group are the true equivalents of our Lower and Upper Ludlow, and contain a number of species in common. The equivalent of the Oriskany Sandstones may be our lowest Devonian. In North America their place is either at the top of the Upper Ludlow or between that and the lowest Devonian rocks, or "Corniferous beds" of the American geologists. We now attempt to analyse the extensive fauna of the Ludlow group, accepting the triple division unconditionally; or, in other words, retaining the Aymestry Limestone as a distinct subformation, not attached either to the Lower or Upper Ludlow; its accidental position carries with it certain fossils having an important bearing upon physical geology.

Plants.—For the first time above the Wenlock we meet with what may be termed plants proper. Five genera and 5 species are known; 4 species occur in the Upper Ludlow, and 3 of the same in the passage-beds between the Upper Ludlow and Lower Old Red Sandstone; none are known in the Lower Ludlow or the Aymestry beds; nowhere in the Ludlow of either South or North Wales, Westmoreland, or Ireland are plant-remains known. *Actinophyllum plicatum* occurs in Shropshire and Herefordshire; *Chondrites verisimilis* is an Upper Ludlow form in Scotland. The seed-like bodies of doubtful affinities (*Pachytheca sphærica*) occur in the tilestones and bone-bed of the uppermost Ludlow of Shropshire, Worcestershire, and Herefordshire. *Actinophyllum* and *Pachytheca* here first occur, and do not pass to higher formations. The passage-beds contain these and

[1] Phyllopoda (*Ceratiocaris* 14 species), Merostomata (*Eurypterus* 10 species, *Hemiaspis* 6, *Pterygotus* 9, *Slimonia* 3, and *Stylonurus* 3).

Pachysporangium pilula. Fifteen species of Crustacea, 19 species of Pelecypoda, 6 of Gasteropoda, 4 of Heteropoda, and 6 species of Fish, or nearly 70 species, illustrate 10 classes in this border-land between the Upper Ludlow and the Old Red Sandstone.

Protozoa.—A series of sponges (Calcispongiæ) numbering 7 genera and 10 species occurs in the Ludlow rocks. Six genera and 8 of the species are Upper Ludlow; *Amphispongia*, *Favospongia*, and *Tetragonis* are new forms, and appear for the first time, and, with *Favospongia Ruthveni*, *Ischadites Kœnigi*, and 4 species of *Spongarium*, die out in the Upper Ludlow. *Favospongia Ruthveni*, *Spongarium æquistriatum*, *S. interlineatum*, *S. interruptum*, and *Tetragonis Danbyi* occur in the Ludlow beds of Westmoreland. The conformable Old Red Sandstone in the Ludlow area, or anywhere along the extended strike and junction of the two formations, contains nothing in common with the Upper Ludlow save a few fish and crustacean remains, all ceasing with the Downton and tilestone beds. The Eurypterids (*Stylonurus megalops* and *Eurypterus pygmæus*) pass to the lower beds of the Old Red Sandstone.

Hydrozoa.—Only 1 genus and 8 species of this class seem left to bring to a close the history of the Rhabdophora. *Monograptus* yields 8 species, which are all Lower Ludlow. In no region of the globe where the Silurian rocks have been deposited have any species of this class transgressed, or passed into higher formations. About 210 species belonging to 30 genera are known in the Silurian rocks, ranging from the Arenig with 42 species, the Llandeilo 44, Caradoc 38, Lower Llandovery 50, Upper Llandovery 12, Wenlock 23, to the Ludlow with 8, their maximum development being at the commencement of the Lower Silurian of certain systematists.[1] They came into existence with unexampled prodigality and suddenness, but gradually died out as conditions grew less and less favourable for their sustenance and development. America, Bohemia, Scandinavia, Australia, and Britain have all largely possessed the same hydrozoal fauna, illustrating the same or similar deposits. Whether homotaxially or not, most of the same genera have occurred in rocks of the same age as those of the British Islands, and always under the same physical conditions.

Actinozoa.—Not a single species out of the 17 occurring in the Ludlow beds strictly belongs or is confined to the Ludlow; all have previously occurred in the Wenlock. Seventeen species are Lower Ludlow; 8 of the same occur in the Aymestry Limestone, and 7 in the Upper Ludlow, chiefly the *Favosites* (5 species). *Monticulipora papillata* is the only Scotch species known. *Favosites aspera*, *F. cristatus*, *F. fibrosus*, *Alveolites Labechii*, *Cyathophyllum truncatum*, and *Monticulipora papillata* occur in Ireland. *Heliolites tubulatus* is the only species known in North Wales.

[1] These specific values are as near the known numbers as the difficulty of determination and distribution will admit.

TABLE XV.—*Geographical Distribution of the Actinozoa.*

Ludlow Species.	South Wales.	North Wales.	Shropshire.	Worcestershire.	Herefordshire.	Westmoreland	Scotland.	Ireland.
Alveolites Labechii	*	...	*	*	*	...	...	*
Cœnites intertextus	...	...	*	...	...	...	...	...
Cyathaxoni siluriensis	...	...	...	...	...	*	...	...
Cyathophyllum truncatum	...	...	*	...	...	...	...	*
Favosites asper	*	...	*	*	*	...	...	*
—— cristatus	...	...	*	...	...	*	...	*
—— fibrosus	*	...	*	*	...	*	...	*
—— gothlandicus	*	...	*	*	*	...	...	...
—— Forbesii	...	...	...	...	...	...	...	...
Fistulipora decipiens	...	...	...	...	...	...	...	...
Halysites catenulatus	*	...	*	*	...	*	...	...
Heliolites interstinctus	*	...	*	*	*	*	...	...
—— tubulatus	...	*	*	*	*	...	...	...
Monticulipora papillata	*	...	...	*	*	*	*	...
Omphyma turbinata	...	...	*	*	*	...	...	*
Petraia bina	*	...	...	*	...	...	...	...
Syringopora bifurcata	...	...	*	*	...	...	...	...
—— serpens	*	...	*	*	...	...	...	...
	9	1	13	12	7	6	1	6

Echinodermata.—This group in the Ludlow comprises 12 genera and 21 species. The Crinoidea are illustrated by *Actinocrinus pulcher*, *Ichthyocrinus pyriformis*, *I. M'Coyanus* and *Taxocrinus d'Orbignyi*. The Cystideans are *Echinocystites pomum*, *E. uva*, *Pseudocrinites magnificus*, and *P. quadrifasciatus*, all Lower Ludlow; 13 are Asteroidea. *Palæaster* (*P. Ruthveni* and *P. hirudo*), *Palæasterina primæva*, and *Protaster Sedgwickii* occur in the Upper Ludlow of Kendal, Westmoreland. *Palæocoma Colvini*, *P. cygnipes*, *P. Marstoni*, *P. vermiformis* are all Lower Ludlow from the Leintwardine beds near Ludlow. *Palæodiscus ferox*, *Protaster leptosoma*, *P. Miltoni*, *P. Sedgwickii*, and *Rhophalocoma pyrotechnica* are from the same horizon and locality; Shropshire thus yielding 8 species of Lower Ludlow starfishes and Westmoreland 4 Upper Ludlow. The Lower Ludlow Echinodermata, therefore, number 11 genera and 19 species, the Upper Ludlow 6 genera and 7 species. In the Ludlow promontory, and all along the line that marks the junction of the Old Red Sandstone with the Upper Ludlow, all Silurian life ceased. The slow elevation of that region caused the Silurian Annuloid fauna to dwindle and pass away almost entirely. No vestige of it again appeared in the true Old Red area anywhere; and the want of evidence to show what rocks may be below the Lower Devonian of the Devonshire and Somersetshire areas, leaves the question of stratigraphical or

zoological continuity one of doubt and in the region of the unknown. Ireland or North Devon may yet solve the problem, for it is here we should expect the solution. The 3 new Ludlow genera were *Echinocystites*, *Palæasterina*, and *Tetragonis*, neither of which leaves any successors behind, none being known either in the Devonian or Carboniferous rocks.

Annelida.—The Annelida are a singular group in the Ludlow rocks; 9 genera and 17 species have been obtained from the horizons (3), and their geographical distribution is wide also. Fifteen species occur in the Upper Ludlow; the characteristic *Cornulites serpularius* being the most abundant, occurring in all 3 horizons, and in all localities except Shropshire and Ireland. The Lower Ludlow has yielded *Cornulites serpularius*, *Serpulites dispar*, *S. longissimus*, *Spirorbis Lewisii*, and *Trachyderma squamosa*.

Crustacea.—The two great orders of the class Crustacea in the Ludlow rocks are the Merostomata and the Phyllopoda. Of the former we know 32 species—*Eurypterus* 10, *Pterygotus* 9, *Himantopterus* 1, *Slimona* 3, *Stylonurus* 3, and *Hemiaspis* 6. Of the latter, through *Ceratiocaris* and *Dictyocaris*, we have 16 species; and possibly one Amphipod (*Necrogammarus Salweyi*) and a Pœcilopod (*Neolimulus falcatus*, Woodw.) These 32 species of Merostomata and Pœcilopoda swell up the Crustacean fauna at the expense of the Trilobita, which number only 10 genera and 20 species, 2 genera only of the 10 (*Homalonotus* and *Phacops*) passing to or occurring in the Devonian rocks. The Ostracoda number 5 genera and only 13 species. The whole Crustacean fauna, therefore, of the Ludlow rocks is 29 genera and 97 species. No Trilobite occurs in the Passage-beds. The Passage-bed Crustacean fauna is here what we should have anticipated; the Brachiopoda and Mollusca proper show the same indications of a change from a deeper to a shallow coast-line, and a fauna struggling to maintain life against new and adverse conditions. Shropshire through the Ludlow area possesses 18 genera and 46 species, Worcestershire 17 genera and 25 species, Herefordshire 14 genera and 26 species, Westmoreland 8 genera and 15 species. Scotland, chiefly through the Phyllopoda and Merostomata, has 12 genera and 22 species. Ireland possesses *Calymene Blumenbachii* and *Phacops caudatus*. This deficiency of the Crustacea in Ireland, as indeed of all the classes except the Brachiopoda, bears out the fact of the smallness of the Ludlow fauna in Ireland. Thirteen new genera first appear during the Ludlow period, viz., 4 Ostracoda, *Cypridina*, *Entomis*, *Kirkbya*, and *Moorea*; 4 Merostomata (Eurypterida), *Himantopterus*, *Slimonia*, *Stylonurus*, and *Parka*, Xiphosura, *Neolimulus* 1, Phyllopoda, *Dictyocaris* 1, Amphipoda 1 ?, *Necrogammarus* 1 species each, *Astacoderma* (14 species). Three genera (*Stylonurus*, *Cypridina*, and *Parka*) occur in the Old Red Sandstone, but not in connected areas. Sixteen genera and 26 species are common to the Wenlock and whole of the Ludlow, thus reducing the true Ludlow Crustacean fauna to 71 species instead of 97.

Polyzoa.—*Heteropora crassa*, *Ceriopora sulcata*, and *Ptilodictya*

lanceolata are the only Ludlow Polyzoa. *Ceriopora sulcata* occurs in the Ludlow of Ireland. The argillaceous nature of the Ludlow shales and mudstones was doubtless the cause why the Actinozoa, Hydrozoa, Echinodermata (Crinoidea, &c.), and Polyzoa, all mostly dwellers in clear water, are so sparingly developed and distributed through the Ludlow rocks, the Aymestry limestone being of little palæontological value owing to its lenticular disposition, mode of occurrence, and uncertain continuity.

Brachiopoda.—The Ludlow Brachiopoda number 13 genera and 48 species; 41 of these 48 had lived in the Wenlock seas and passed to the Ludlow; therefore only 7 species are Ludlow proper, and only 3 passed to the Devonian—*Atrypa reticularis*, *Strophomena rhomboidalis*, and *Lingula cornea*.

The only species in the Ludlow not Wenlock are *Lingula cornea*, *L. lata*, *Orthis canaliculata*, *O. lunata*, *Rhynchonella pentlandica*, and *Strophomena ornatella*. In other words, only these 6 species of Brachiopoda are really Ludlow forms. No species is known in North Wales, but 28 have been collected in South Wales.

Pelecypoda.—Both the Lower and Upper Ludlow possess a large Molluscan fauna; the Lower 14 genera and 34 species, and the Upper 15 genera and 56 species; the intermediate Aymestry limestone only 4 genera and 7 species—*Pterinæa hians*, *P. retroflexa*, *P. Sowerbyi*, *Cardiola striata*, *Grammysia cingulata*, *Orthonota rotundata*, and *O. semisulcata*. The chief genera are *Pterinæa* with 12 species, *Anodontopsis* 7, *Orthonota* 16, *Modiolopsis* 5, *Ctenodonta* 4, *Cucullæa* 4, and *Grammysia* 4 species. The Passage-beds contain 9 genera and 19 species, yet *no single species passes to or occurs in* the Lower Old Red Sandstone; with the change in lithological characters all life seems to cease also, or no record is left. For the life-history of those rocks, equivalent in time to the Old Red Sandstone in the classical Silurian area and Scotland, we have to consult the Devonian series of North and South Devon and Cornwall, where a fauna unsurpassed in perfection, if not in magnitude, in all the invertebrate classes exists—a group made famous in British geological history through the labours and researches of Sedgwick, Murchison, De la Beche, and Phillips. Westmoreland and Cumberland, through the researches of Sedgwick and M'Coy, Harkness and Nicholson, in the Kendal area, exhibit a large Ludlow Pelecypod fauna; 12 genera and 37 species being known.

Extensive patches of Upper Silurian rocks on the eastern side of the Silurian area and border of the Old Red Sandstone, such as Woolhope, Usk, the long strike of the Malverns on to May Hill, thence across the Severn at Purton Passage to Tortworth, indicate great physical changes in the borderland between the fossiliferous Upper Silurian and the unfossiliferous Old Red Sandstone; and whatever change brought in the marine Devonian of North Devon, south of the Mendip axis and on the same strike, and all the South Wales Old Red Sandstone beneath the South Wales coal-field to the Bristol Channel, certainly must account for the loss of all the Ludlow species.

That the Devonian area was one of long and continuous depression south of the latitude of the Mendips there cannot be any doubt, and probably the great mass of Old Red Sandstone occupying Caermarthenshire, Monmouthshire, Breconshire, Herefordshire, and Worcestershire was being slowly elevated at the same time.

Gasteropoda.—Nine genera and 33 species (6 of which had appeared in the Wenlock) range through the Ludlow rocks; the Lower Ludlow has yielded 8 genera and 15 species, the Aymestry limestone 5 genera and 11 species, and the Upper Ludlow 9 genera and 21 species. The Passage-beds into the Old Red Sandstone contain *Holopella conica*, *H. gregaria*, *Holopæa obsoleta*, *Murchisonia torquata*, *Platyschisma helicites*, and *P. Williamsi*. They, however, cease here, none living into the red beds of the Old Red Sandstone. North Wales has yielded *Holopella gracilior* and *H. gregaria;* Scotland only 4 species, *Acroculia antiquata*, *Euomphalus funatus*, *Platyschisma simulans*, and *P. helicites;* Ireland has only registered 1 species, *Euomphalus alatus;* Herefordshire 7 genera and 11 species; Worcestershire 6 genera and 9 species; Shropshire 7 genera and 14 species; and Westmoreland 6 genera and 14 species. Six genera and 13 of the 33 species pass up from the Wenlock and range through the Ludlow rocks; they are *Acroculia haliotis*, *Cyclonema corallii*, *C. octavia*, *Euomphalus alatus*, *Ecarinatus*, *E. funatus*, *E. rugosus*, *Holopella gracilior*, *H. obsoleta*, *Loxonema elegans*, *L. sinuosa*, *Murchisonia Lloydii*, and *M. articulata*. Nine species only are Lower Ludlow. All become extinct in the Tile-stones and Passage-beds.

Pteropoda.—*Conularia subtilis* and *C. Sowerbyi*, with *Theca Forbesii*, illustrate this pelagic group. The two last named are Upper Ludlow. *Conularia Sowerbyi* occurs in Scotland; all 3 species in Westmoreland, and *Theca Forbesii* and *Conularia Sowerbyi* in Shropshire. These last are also Wenlock species.

Heteropoda.—*Bellerophon* (6 species) and *Ecculiomphalus lævis* constitute the Ludlow Heteropoda. *Ecculiomphalus lævis*, *Bellerophon expansus*, and *B. dilatatus* occur both in the Lower and Upper Ludlow. *B. Murchisoni*, *B. obtectus*, and *B. trilobatus* are Upper Ludlow only; *B. carinatus*, *B. expansus*, *B. Murchisoni*, and *B. trilobatus* occur in the Passage-beds; 6 species occur in the Upper Ludlow of Westmoreland; Shropshire and Worcestershire possess 3 of the same species. None are known in the Ludlow rocks of North Wales, Herefordshire, Scotland, or Ireland. *B. carinatus*, *B. trilobatus*, and *B. dilatatus* are also Wenlock species.

Cephalopoda.—No less than 24 species of *Orthoceratites*, 6 species of *Phragmoceras*, and 3 of *Lituites*, with other forms, make up the 6 genera and 37 species known in the Ludlow. *Ascoceras Barrandii* constitutes a new generic type for Britain. The Lower Ludlow has yielded *Lituites* (3 species), *Orthoceras* (15), *Phragmoceras* (6), and *Exosiphonites* (2 species).

Lituites giganteus, *Orthoceras* (4 species), and *Phragmoceras ventricosum* occur in the Aymestry limestone. The Upper Ludlow contain 5 genera and 22 species—*Ascoceras Barrandii*, *Lituites giganteus*,

Orthoceras (17 species), *Phragmoceras nautileum*, and *Tretoceras semipartitum*.

In the Passage-beds we have noted *Orthoceras bullatum* and *Tretoceras semipartitum*. Sixteen species of the genus *Orthoceras* occur in Westmoreland, mostly Upper Ludlow, and no other genus has yet occurred there. Shropshire possesses 4 genera and 22 species, Herefordshire 5 genera and 21 species, *Ascoceras Barrandii*, *Lituites* 3 species, *Orthoceras* 11, *Phragmoceras* 3, *Exosiphonites* 2, and Worcestershire 10 species. *Orthoceras Maclareni* and *O. subgregarium* are the only Scotch forms known, and *O. subgregarium* is the only Irish species. *Ascoceras* is the only new genus, *and none ranged higher or into either Old Red Sandstone*, Devonian, or Carboniferous rocks.

Pisces.—No vertebrata have yet been discovered in earlier rocks than the Lower Ludlow. *Scaphaspis* (*Pteraspis*) *ludensis*, Salt., is the first fish known, and the only species in the Lower Ludlow; none have yet been detected in the Aymestry limestone, but every known Ludlow form occurs in the Upper Ludlow, and 5 of them in the passage or junction beds, through which about 20 species in the Silurian fauna pass to the Lower Old Red Sandstone, 7 of which are Crustacea (Merostomata), 6 fishes, and 2 Cephalopoda, &c.

The Crustacea common to the Ludlow and Old Red Sandstone, and all belonging to one order, are *Eurypterus abbreviatus*, *E. acuminatus*, and *E. pygmæus*, *Pterygotus problematicus*, *Stylonurus Powriei*, *S. megalops*, and *Parka decipiens*. The fishes that connect the two formations, *but only in the Silurian area along the frontier* of the Old Red Sandstone, are *Auchenaspis Salteri*, *Cephalaspis Murchisoni*, *C. ornatus*, *Pteraspis Banksii*, *Scaphaspis* (*Pteraspis*) *ludensis*, and *Eukeraspis* (*Sclerodus*) *pustuliferus*. All belong to the Ganoidei.

Tabular View of the Cambrian and Silurian Strata, with Physical and Palæontological Particulars.

UPPER SILURIAN.	LUDLOW GROUP.	Passage-beds, Tilestones, and Downton Sandstones.	A series of greenish-grey shales, containing lenticular pockets of hard grey grit; with abundance of Crustacean and plant remains, *Lingula cornea*, and fish fragments.
			Thin-bedded yellowish sandstones, with Crustacean (Pœcilopod), plant and fish remains, *Lingula cornea?* var. *minima* (Sow.), *Orthoceras*, *Platyschisma helicites*, *Modiolopsis*, *Beyrichiæ*, &c. Loc. Ledbury, Ludlow, Downton, Kington, Lesmahago.
		Upper Ludlow Rock.	Yellowish, greenish, and grey argillaceous sandy mudstone, with calcareous lenticular and nodular masses, and many species of Brachiopoda, *Chonetes lata*, *Rhynchonella nucula*, *Discina rugata*, *Orthis lunata*, and *O. elegantula*, with *Orthonota amygdalina*. *Serpulites longissimus*, &c. Loc. Whitcliffe, Ludlow, Malvern, Longhope.
		Aymestry Limestone.	Grey, pale-yellow, or brown shales, with bands of argillaceous limestone in the upper part, and containing great numbers of *Strophomena filosa*, *St. depressa*, *Rhynchonella nucula*, *Rh. navicula*, and *Lingula Lewisii*; the lower portion also consisting of beds of argillaceous limestone, filled with *Pentamerus Knightii*, *P. galeatus*, *Strophomena euglypha*, *Atrypa reticularis*, *Lingula striata*, with *Proetus Stokesii*, *Phacops caudatus*, &c. Loc. Whitcliffe, Aymestry, View Edge, Onibury.
		Lower Ludlow Shale.	Yellowish-grey hard flaggy and nodular argillaceous shales, with occasional beds of impure limestone, and containing concretionary nodules of fossiliferous blue limestone; the upper portion contains *Lingula lata*, *Graptolites Ludensis*, and *Cardiola interrupta*; in the middle portion *Phragmoceras* and *Lituites* occur; and in the lower *Phacops*, &c. Loc. Vinnal Hill, Mocktree, Stokes Wood, Onibury.
	WENLOCK GROUP.	Wenlock Limestone.	Argillaceous or semi-crystalline limestone, and lenticular masses of concretionary matter, abounding in organic remains, especially Crinoidea, Cœlenterata, Crustacea, and Brachiopoda; *Spirifera plicatella*, *Sp. elevata*, *Athyris tumida*, *Atrypa reticularis*, *Rhynchonella Stricklandii*, *Rh. borealis*, *Rh. Wilsonii*, *Orthis rustica*, *Strophomena antiquata*, *Discina Forbesii*, and *Obolus Davidsonii*, being most typical. Loc. Wenlock Edge, Dudley, Walsall, May Hill, &c.

UPPER SILURIAN.	WENLOCK GROUP.	Wenlock Shale.	Hard flaggy beds and thin shales, in places slaty, with occasional beds of sandstone; fossils resembling those above. Loc. Wenlock, Dudley, Walsall, Malvern, Usk, &c.
		Woolhope Beds.	Dark-grey, semi-indurated limestone, with much carbonate of lime in veins, and occasional bands of argillaceous nodules, &c., also sandy beds in places; *Illœnus* (*Bumastus*) *Barriensis*, *Orthis Davidsoni*, *O. elegantula*, var. Loc. Woolhope, Walsall, &c.
		Denbighshire Grits and Tarannon Slates.	Thin-bedded flaggy sandstones and slaty beds; fossils comparatively rare in places, especially in the gritty beds. Loc. Flintshire, Denbighshire. Tarannon river-banks, &c.
		Upper Llandovery.	Grey and yellowish sandstones (occasionally conglomerates), with bands of limestone; rich in organic remains, especially Brachiopoda; *Pentamerus oblongus*, *Rhynchonellæ*, *Orthides*, &c. Loc. May Hill, Shelve, Tortworth, &c.
LOWER SILURIAN.		Lower Llandovery.	Hard sandstones, conglomerates, and flaggy shaly beds; the fossils closely allied to those of the Upper Llandovery series; but distinguished by *Pentamerus* (*Stricklandima*) *lens*, and by unconformity.
		Caradoc or Bala Rocks.	Shelly sandstones, shales, and slaty beds, with quartzose grits, conglomerates, and occasional limestone or calcareous bands; fossils numerous, especially Echinodermata, Crustacea (Trilobites), Polyzoa, and Brachiopoda; of the last nearly fifty species, including *Orthis Actoniæ* and *O. flabellulum*. Loc. Caradoc, Horderley, Norbury, Bala, Snowdon, Wexford, Kildare.
		Llandeilo Flags.	Dark-grey flagstones, occasionally calcareous, with black slates containing *Graptolites*, &c. The Llandeilo flags contain *Lingulæ*, *Obolellæ*, *Discinæ*, and *Orthidæ*, with the well-known Trilobites *Ogygia Buchii*, *Asaphus tyrannus*, and *Trinucleus concentricus*. Loc. Llandeilo, Builth, &c.
		Arenig or Stiperstone Group.	Dark slates, shales, and flags, and thin sandstones (developed in the Arenig mountains), associated with porphyry. *Æglina*, *Illœnopsis*, *Barrandia*, *Illœnus*, *Calymene*, *Conularia*, *Theca*, and many genera of Rhabdophora. Loc. St. David's, Tremadoc area, Stiperstones, Skiddaw, &c.

CAMBRIAN.	Tremadoc Slates.	Dark-grey and ferruginous slates, sandy shales, and hard bluish flags, with occasional beds of pisolitic iron ore, much felspathic matter in lines and thin beds; the Lower and Upper Tremadoc slates contain numerous genera of Trilobites, *Ogygia scutatrix*, *Asaphus Homfrayi*, *Æglina*, *Trinucleus*, &c., also Heteropod and Pteropod Mollusca, &c., with Graptolites (*Diplograpsus pristis* and *D. folium*), *Orthis alata* and *O. testudinaria*. Loc. Stiperstones, Tremadoc, Portmadoc, Ffestiniog, Dolgelly, Dudreath, &c.
	Lingula Flags.	A great series of black and dark shales, grey and brown thin slaty flagstones and sandstones, with silicious grits and quartzites (Stiperstones); occasionally crowded with fossils, and always having the characteristic *Lingula* (*Lingulella*) *Davisii*. It is equally remarkable for its Crustacea (*Paradoxides*, *Oleni*, *Agnosti*, *Hymenocaris*, &c.) Loc. Dolgelly, Barmouth, Ffestiniog, St. David's, &c.
	Lower Cambrian.	Dark-green, grey, black, and brown flags, also grits and conglomerates. occurring at Harlech, Anglesea, Llanberris, St. David's, the Longmynd, &c., with few fossils.
	Laurentian Rocks.	"Fundamental Gneiss" of Murchison. Western promontories of Ross and Sutherland, the Lewis, or Long Island, including Harris, and other parts of the Hebrides.

TABLE XVI.—ORGANIC REMAINS OF THE LOWER PALÆOZOIC STRATA.

(The Genera are arranged alphabetically, the number of Species brought down to the present date.)

KINGDOM—PLANTÆ?

OLDHAMIA? CALCYPHITE?—*See* HYDROZOA.

SUB-KINGDOM—PROTOZOA.

Genera.	No. of Species.	Cambrian.[1]	Lower Silurian.	Upper Silurian.
Acanthospongia	1	...	1	...
Amphispongia	1	...	...	1
Astylospongia	2	...	2	...
Clathrodictyon	1	...	...	1
Cliona	1	...	...	1
Cnemidium	1	...	...	1
Dictyophyton	1	...	...	1
Favospongia	1	...	...	1
Hyalostilia	2	...	2	...
Ischadites	2	...	2	1
Nidulites	2	...	2	...
Plectoderma	1	...	...	1
Protospongia	4	4	...	...
Sphærospongia	1	...	1	...
Spongarium	4	...	1	4
Stromatopora	1	...	1	1
Tetragonis	1	...	...	1
17	27	4	12	14

SUB-KINGDOM—CŒLENTERATA.

Class—ACTINOZOA.

Acervularia	1	...	...	1
Alveolites	4	...	1	4
Arachnophyllum	1	...	...	1
Aulacophyllum	1	...	1	1
Calostylis	1	...	1	...
Chonophyllum	1	...	...	1
Clisiophyllum	1	...	...	1
Cœnites	5	...	...	5
Cyathaxonia	1	...	...	1
Cyathophyllum	7	...	3	7
Cystyphyllum	5	...	1	5
Favosites	10	...	8	8
Fistulipora	1	...	1	1
Goniophyllum	1	...	...	1
Halysites	2	...	1	1
Heliolites	10	...	5	10
Labechia	1	...	...	1

[1] The term "Cambrian," as used here, embraces all the strata up to the close of the Tremadoc rocks, the "Lower Silurian" commencing with the Arenig series and terminating with the close of the Lower Llandovery, all above being "Upper Silurian."

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Lindströmia	1	...	...	1
Monticulipora (Chætetes)	8	...	5	4
Nebulipora	1	...	1	...
Omphyma	3	...	1	3
Palæocyclus	4	...	2	4
Petraia	7	...	6	7
Pinnacopora	1	...	...	1
Plasmopora	2	...	1	2
Propora	1	...	...	1
Prosopora	1	...	1	...
Ptychophyllum	1	...	...	1
Stenopora	2	...	2	1
Streptelasma	1	...	...	1
Strombodes	4	...	1	4
Stylaræa	1	...	1	...
Syringophyllum	1	...	1	1
Syringopora	5	...	1	5
Thecia	2	...	...	2
Thecostegites	1	...	1	...
Tretadium	1	...	1	...
Zaphrentis	1	...	...	1
38	102		47	88

Class—HYDROZOA.

Azygograptus	1	...	1	...
Bryograptus	1	1	...	...
Callograptus	4	...	4	...
Clematograptus	1	...	1	...
Climacograptus	10	...	10	...
Clonograptus	1	1	...	...
Corynoides	2	...	2	...
Cyrtograptus	1	...	...	1
Dendrograptus	12	...	11	1
Dicellograptus	5	...	5	...
Dichograptus	7	...	7	...
Dicranograptus	5	...	5	...
Dictyograptus	3	...	3	...
Didymograptus	21	..	21	...
Diplograptus	34	...	34	...
Glossograptus	1	...	1	...
Helicograptus	1	...	1	...
Leptograptus	1	...	1	...
Loganograptus	1	...	1	...
Monograptus (Graptolithus)	30	...	23	7
Nemagraptus	1	...	1	...
Oldhamia	2	2	...	...
Pleurograptus	2	...	2	...
Phyllograptus	3	...	3	...
Protovirgularia	2	...	2	...
Ptilograptus	5	...	3	2
Tetragraptus	7	...	7	...
Thamnograptus	1	...	1	...
Trigonograptus	3	...	3	...
Rastrites	5	...	5	...
Retiolites	3	...	3	1
31	176	4	161	12

Sub-Kingdom — ANNULOIDA.

Class—Echinodermata.

Family *Crinoidea*.

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Actinocrinus	4	...	2	3
Bdellacoma	1	...	...	1
Cheirocrinus	4	...	...	4
Cophinus	1	...	...	1
Crotalocrinus	1	...	...	1
Cyathocrinus	5	...	...	5
Dendrocrinus	1	1	...	...
Dimerocrinus	2	...	...	2
Ennalocrinus	2	...	...	2
Eucalyptocrinus	3	...	...	3
Eucladia	1	...	...	1
Eugeniacrinites	2	...	...	2
Glyptocrinus	4	...	3	2
Ichthyocrinus	2	...	...	2
Marsupiocrinus	1	...	...	1
Periechocrinus	4	...	...	4
Pisocrinus	2	...	...	2
Platycrinus	3	...	...	3
Sagenocrinus	2	...	...	2
Taxocrinus	7	...	...	7
Tetramerocrinus	1	...	...	1
21	53	1	5	49

Family—*Cystidea*.

Agelacrinites	1	...	1	...
Atelocystites	2	...	1	1
Apiocystites	1	...	...	1
Caryocystites	5	...	5	...
Cyclocystoides	1	...	...	1
Echinoencrinites	2	...	...	2
Echinocystites	2	...	...	2
Echinosphærites	5	...	5	...
Glyptocystites	1	...	1	...
Hemicosmites	4	...	4	...
Macrocystella	1	1	...	...
Protocystites	1	1	...	...
Prunocystites	1	...	...	1
Pseudocrinites	4	...	...	4
Pleurocystites	1	...	1	...
Sphæronites	5	...	5	...
16	37	2	23	12

Family—*Asteriadæ*.

Lepidaster	1	...	...	1
Palæaster	7	...	4	3
Palæasterina	2	1	...	1
Palæocoma	4	...	...	4
Palæodiscus	1	...	...	1
Protaster	4	...	1	3
Rhophalocoma	1	...	...	1
Uraster	4	...	1	3
8	24	1	6	17

Family—*Echinoidea.*

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Palæchinus	1	...	...	1
Sub-Kingdom—ANNULOSA.				
Class—Annelida.				
Arabellites	2	...	...	2
Arenicolites	3	2	1	...
Conchicolites	1	...	1	...
Cornulites	1	...	1	1
Crossopodia	2	...	1	1
Cruziana	1	1	...	...
Dexolites	1	...	1	...
Haughtonia	1	1	...	...
Helminthites	1	...	1	1
Histioderma	1	1	...	...
Lumbricaria	2	...	2	...
Myrianites	2	...	2	...
Nemertites	1	...	1	...
Nereites	3	...	3	...
Palæochorda	3	...	3	...
Pyritonema	1	...	1	...
Salterella	1	...	1	...
Scolecoderma	2	2	...	...
Scolites	1	1	...	...
Serpulites	5	1	1	4
Spirorbis	1	...	...	1
Stella-scolites	1	...	1	...
Tentaculites	4	...	3	3
Trachyderma	4	...	2	2
Trichoides	1	...	1	..
25	46	9	27	15
Sub-Kingdom ANNULOSA.				
Class—Crustacea.				
Family—*Trilobita.*				
Acidaspis	13	...	8	7
Æglina	8	...	8	...
Agnostus	20	15	5	...
Amphion	3	...	3	...
Ampyx	9	1	7	1
Angelina	2	2	...	...
Anopolenus	3	3	...	...
Aptychopsis	3	...	3	...
Arionellus	1	1	...	...
Asaphus	17	3	16	...
Astacoderma	14	...	...	14
Barrandia	5	...	5	...
Bronteus	2	...	1	1
Calymene	16	...	14	5
Carausia	1	1	...	...
Cheirurus	9	1	9	1
Conocoryphe	21	21	...	...
Conophrys	1	1	...	..
Cybele	3	...	3	...
Cyphaspis	3	...	...	3
Cyphoniscus	1	...	1	...
Deiphon	1	...	...	1
Dikelocephalus	4	4	...	...
Dionide	1	1	1	...

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Encrinurus	4	...	3	2
Erinnys	1	1	...	...
Harpes	3	...	3	...
Holocephalina	2	2	...	...
Homalonotus	13	...	8	5
Illænopsis	1	...	1	...
Illænus	21	...	17	7
Lichapyge	1	1	...	...
Microdiscus	2	2	...	...
Nesuretus	4	4	...	...
Niobe	4	3	1	...
Lichas	13	...	6	8
Ogygia	9	3	9	...
Olenus	16	16	...	...
Paradoxides	5	5	...	...
Palæopyge	1	1	...	...
Parabolina	1	1	...	...
Parka	1	...	...	1
Phacops	28	...	22	6
Peltura	1	...	...	1
Proëtus	2	...	1	2
Placoparia	1	...	1	...
Platypeltis	1	1	...	...
Plutonia	1	1	...	...
Psilocephalus	2	2	...	...
Remopleurides	7	...	7	...
Salteria	2	...	2	...
Sphærexochus	2	...	2	1
Sphærophthalmus	1	1	...	...
Staurocephalus	5	...	5	1
Stygina	3	...	3	...
Tiresias	1	...	1	...
Trinucleus	12	...	12	1
57	332	98	188	68

Class—ENTOMOSTRACA and PHYLLOPODA.

Æchmina	2	...	...	2
Bairdia	4	...	3	1
Beyrichia	7	...	6	3
Caryocaris	1	...	1	...
Ceratiocaris	16	2	1	13
Cythere	7	...	5	2
Cypridina	1	...	...	1
Cytherellina	3	...	...	3
Dictyocaris	2	...	...	2
Discinocaris	1	...	1	...
Entomis	4	1	...	3
Hymenocaris	1	1	...	...
Kirkbya	1	...	...	1
Leperditia	4	4	...	1
Lingulocaris	1	1	...	...
Moorea	1	...	...	1
Myocaris	1	1	...	...
Necrogammarus	1	...	...	1
Peltocaris	3	...	3	...
Primitia	26	2	11	13
Thilipsura	3	...	...	3
21	90	12	31	50

Class—MEROSTOMATA.

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Eurypterus	10	...	...	10
Hemiaspis	6	...	...	6
Himantopterus	1	...	...	1
Neolimulus	1	...	...	1
Pterygotus	9	...	...	9
Slimonia	1	...	...	1
Stylonurus	2	...	...	2
7	30	...	...	30

Family—*Cirripedia.*

Turrilepas	1	...	...	1

SUB-KINGDOM—MOLLUSCOIDA.

Class—POLYZOA.

Berenicea	1	...	1	...
Cellepora	1	...	...	1
Ceriopora	4	...	...	4
Diastopora	3	...	...	2
Dictyonema	1	1	...	...
Discopora	3	...	...	3
Escharina	1	...	...	1
Fenestella	11	...	5	8
Glauconome	1	...	1	...
Heteropora	1	...	...	1
Intricaria	1	...	1	...
Polypora	1	...	...	1
Ptilodictya	8	...	7	5
Retepora	4	...	3	2
14	41	1	18	28

SUB-KINGDOM—MOLLUSCA (*Molluscoida*).

Class—BRACHIOPODA.

Acrotreta	1	...	1	...
Athyris	3	...	...	3
Atrypa	10	...	5	8
Chonetes	3	...	1	2
Crania	5	...	2	3
Cyrtia	1	...	...	1
Dinobolus	1	...	1	...
Discina	13	2	6	5
Eichwaldia	2	...	...	2
Kutorgina	1	1	...	...
Leptæna	42	...	23	17
Lingula	27	3	16	11
Lingulella	4	4	...	...
Meristella	9	...	3	7
Nucleospira	1	...	...	1
Obolella	6	4	2	...
Obolus	3	...	...	3
Orbiculoidea	2	...	...	2
Orthis	67	3	54	22
Orthisina	1	...	1	...
Pentamerus	7	...	3	7
Porambonites	1	...	1	...

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Retzia	2	...	...	2
Rhynchonella	25	...	13	15
Siphonotreta	2	..	1	1
Spirifera	10	...	2	8
Spondylobolus	1	1	...	...
Stricklandinia	2	...	2	2
Strophomena	40	...	28	21
Triplesia	4	...	4	1
30	296	18	174	144

SUB-KINGDOM—MOLLUSCA (*Conchifera*).

Class—PELECYPODA (*Lamellibranchiata*).

Ambonychia	9	...	8	1
Anodontopsis	7	...	...	7
Arca	5	...	2	3
Avicula	4	...	1	3
Cardiola	4	...	2	3
Cleidophorus	3	...	2	1
Conocardium	3	...	2	1
Ctenodonta	29	2	18	9
Cucullella	5	...	2	4
Davidia	2	2	...	...
Dolabra	2	...	...	2
Glyptarca	2	2	...	...
Goniophora	1	...	...	1
Grammysia	4	...	...	4
Lunulacardium	6	...	2	4
Lyrodesma	2	...	1	1
Megalomus	1	...	1	...
Modiolopsis	22	4	14	9
Mytilus	6	...	3	4
Orthonota	21	...	5	18
Palæarca	10	2	7	1
Pterinæa	20	...	8	13
Redonia	1	...	1	...
Ribieria	1	...	1	...
Solen?	1	...	...	1
25	171	12	80	90

Class—PTEROPODA.

Conularia	10	1	8	3
Cyrtotheca	1	1	...	...
Pterotheca	3	...	3	...
Stenotheca	1	1	...	...
Theca	21	13	8	2
5	36	16	19	5

Class—GASTEROPODA.

Acroculia	4	...	1	3
Cyclonema	10	...	5	6
Euomphalus	17	...	9	10
Eunema	1	...	...	1
Holopea	7	...	7	...
Holopella	9	...	4	8

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Loxonema	3	...	1	2
Macrocheilus	2	...	1	1
Murchisonia	24	...	16	8
Natica	1	...	...	1
Ophileta	2	...	2	...
Patella	1	...	1	...
Platyschisma	3	...	2	3
Pleurotomaria	9	...	5	4
Raphistoma	5	...	5	2
Trochus	3	...	2	2
Turbo	2	...	2	1
Trochonema	4	...	4	2
18	107	...	67	54

Class—HETEROPODA.

Bellerophon	22	5	14	10
Ecculiomphalus	3	...	2	2
Maclurea	5	...	5	...
3	30	5	21	12

Class—CEPHALOPODA.

Actinoceras	3	...	...	3
Ascoceras	1	...	...	1
Cyrtoceras	7	1	6	1
Endoceras	1	...	1	...
Exosiphonites	2	...	...	2
Koleoceras	3	...	3	...
Lituites	9	...	5	5
Oncoceras	1	...	1	...
Orthoceras	71	1	45	35
Phragmoceras	6	...	1	6
Piloceras	1	...	1	...
Poterioceras	1	...	1	...
Tretoceras	2	...	1	1
Trocholites	1	...	1	...
14	109	2	66	54

SUB-KINGDOM—VERTEBRATA.

Class—PISCES.

Auchenaspis	2	...	...	2
Cephalaspis	3	...	...	3
Eukeraspis	2	...	...	2
Onchus	2	...	...	2
Plectrodus	2	...	...	2
Pteraspis	2	...	...	2
Scaphodus	1	...	...	1
Sphagodus	1	...	...	1
Thelodus	1	...	...	1
Thysetes	1	...	...	1
Scaphaspis	2	...	...	2
11	19	...	...	19

TABLE XVII.—Showing the Numerical History of the Lower Palæozoic Series.

	Cambrian.[1]				Lower Silurian.				Upper Silurian.					Passage Beds.	Pass to
	Harlech and Longmynd Rocks.	Menevian.	Lingula Flags.	Tremadoc.	Arenig.	Llandeilo.	Caradoc or Bala.	Lower Llandovery.	Upper Llandovery.	Wenlock, including Woolhope Beds, Wenlock Limestone, and Wenlock Shale.	Lower Ludlow.	Aymestry Limestone.	Upper Ludlow.	Passage Beds.	Old Red Sandstone or Devonian.
Plantæ	?	...	...	...	...	...	...	...	1/1	...	...	...	1/1	2/2	...
Protozoa	1/2	1/1	1/1	...	...	1/1	9/15	2/7	2/2	4/4	...	4/5	4/6	...	...
Hydrozoa	2/2	...	...	2/2	18/42	18/44	24/59	7/20	6/11	1/1	1/1	...	...	...	...
Actinozoa	...	...	...	...	...	2/5	20/40	12/25	14/23	26/76	12/17	7/13	2/7	...	...
Echinodermata	...	1/1	...	2/2	...	4/4	18/33	2/2	2/5	28/68	1/1	3/3	2/2	1/1	...
Annelida	4/6	2/3	6/8	...	9/11	6/9	11/15	2/2	2/4	16/36	4/6	2/2	7/15	2/2	1/1
Crustacea	7/13	12/32	14/51	24/36	14/48	20/45	87/140	12/15	11/24	27/78	1/2	2/2	22/58	6/16	4/7
Polyzoa	...	...	1/1	1/1	...	...	7/21	2/5	2/7	11/42	2/2	...	...	...	...
Brachiopoda	2/6	4/6	1/2	1/5	7/15	10/34	15/109	10/56	12/16	28/101	12/12	12/16	1/1	1/2	2/2
Pelecypoda	...	...	...	1/2	4/8	5/8	10/76	3/3	12/25	16/44	1/2	4/7	1/5	2/15	...
Gasteropoda	...	...	...	...	1/4	2/3	12/58	2/2	12/25	2/17	2/2	1/1	2/11	1/8	...
Pteropoda	1/2	2/6	1/2	3/12	2/8	1/3	3/16	1/1	1/1	2/2	2/2	...	3/3	...	...
Heteropoda	...	...	1/1	2/4	1/1	2/2	2/17	1/2	1/1	2/2	1/1	1/1	1/1	1/1	...
Cephalopoda	...	...	...	2/2	1/4	2/7	8/47	3/5	6/19	6/30	2/5	2/5	5/13	2/2	1/2
Pisces	...	...	...	...	...	...	...	...	...	...	1/1	...	2/16	1/6	1/6
Genera	18	23	30	51	60	80	179	68	91	170	96	53	102	40	14
Species	31	52	74	93	147	175	614	204	261	529	219	84	246	64	19

[1] This Table embraces the complete numerical history of the Lower Palæozoic series, from the Harlech and Longmynd rocks to the close of the Silurian and Passage-beds into the Old Red Sandstone or Devonian. The grouping adopted is that of all the previously prepared Tables. The figures through the Table express the number of genera and species in each class and geological horizon. The upper, or numerator, gives the number of *known* genera, and the lower, or denominator, the number of *known* species. Sir C. Lyell and most systematists commence the Lower Silurian rock, as in this table, with the Arenig group, and the Upper Silurian with the May Hill Sandstone or Upper Llandovery.

PART II.

CHAPTER XVIII.

DEVONIAN AND OLD RED SANDSTONE.

Introduction.

In the limited area of the British Islands, to which we shall mostly confine our history, the Middle Palæozoic or Old Red Sandstone series exhibits two clearly marked types—one the Scottish and Welsh types of Old Red Sandstone and marls, poorly fossiliferous, save in fishes in Scotland; the second, the Devonian and Cornish type, consisting of slates, red and grey sandstones, compact crystal line and earthy limestones, which in places are rich in marine fossils. This type occurs in many parts of Europe, especially in Belgium, Russia, and Germany, and is well identified in North America, Africa, &c.

Scottish Type.—(a.) **The Lower Old Red Sandstone** occurs on the north side of the Grampians, and on the north-west side of the Lammermuirs, chiefly as a mass of conglomerate and red sandstone. It occupies the whole of the broad belt of undulating country from Stonehaven to the mouth of the Eden, and thence south-west to Stirling, Callender, and Menteith. At Lesmahago, on the south side of the Firth of Forth, the lowest portion of the Old Red occurs, where it passes down into the Upper Silurian. Crustacea (Pterygotus) and fish-remains, Cephalaspis, Dipterus, and Coccosteus, with fragmentary plants, occur in the flagstones and sandstones.

(b.) **The Upper Old Red Sandstone** in Scotland occurs as patches in red and yellow sandstone. At Elgin the bones and scales of *Bothriolepis* and *Holoptychius*, with other characteristic fishes, occur. On the south side of the Forth it covers a large part of Haddingtonshire, Berwickshire, and Roxburghshire, usually resting upon the eroded or worn edges of the Silurian rocks, and covered by the Carboniferous series. In Ayrshire it appears associated with contemporaneously ejected igneous rocks, and extends from the head of Ayr southwards to the valley of the Girvan.

Welsh Type of Old Red Sandstone.—Along the south-eastern and southern border of the older Palæozoic district of Wales, from Coalbrook Dale through Herefordshire, Monmouthshire, Glamorganshire, and Pembrokeshire, the Old Red Sandstone is of vast thickness, fully developed, extensively spread, composed of definite parts, and regularly traceable through the country. Its boundary on the west is by Haverfordwest, Caermarthen, Llandovery, Knighton, and Ludlow. On the east it ranges from near Cardiff, by the high district of Wentwood, Trelech, and Craig-y-Dorth, and by the Forest of Dean, which it encircles with a high ridge, and west of Mayhill, the Malvern and Abberley hills, to the Severn near Bewdley. Its thickness in Monmouthshire and Breconshire can hardly be estimated at less than from 6000 to 8000 feet, but its lower portion is not always clearly distinguishable from the Silurian strata beneath. In fact, near Langaddoc, the marly beds of the Lower Old Red Sandstone alternate with true Silurian strata, containing characteristic fossils. From the Carboniferous limestone series above it is in general sharply defined. In the district of Tortworth and the Forest of Dean, a yellowish sandstone appears along the junction line.

Monmouthshire, &c.—One of the best sections of the Old Red Sandstone is afforded in the neighbourhood of Monmouth, beginning with the Kymin Hill, which is part of the lofty boundary of Dean Forest. Here the thick conglomerate is full of quartz pebbles, remarkably analogous to some varieties of millstone grit, and forms the very cap of the whole system, crowning the hills with magnificent precipices and solitary crags. Below is a series of red sandstones, productive of excellent flagstone, with one or two beds of a singular limestone, mottled with red, blue, green, and yellow, sometimes much mixed with clays, and always irregular. Though of argillaceous aspect, it is so nearly pure as to be burned for lime. No organic remains occur in this vicinity, but elsewhere fragments of Cephalaspis, Holoptychius, and other fishes occur in it. The lowest part of the section exhibits an extreme abundance of red marls with white and green bands, hardly distinguishable from those of the New Red marl. The upper conglomerates are worked and converted into cider millstones, and the limestone (called cornstone) is often employed as road metal. This limestone, indeed, notwithstanding its apparently irregular and fragmentary character, is one of the most persistent layers; it characterises the Old Red Sandstone along nearly its whole course. In Caermarthenshire it is remarkable in the cliffs near Laugharne and Ferryside, from which place have been obtained many specimens of *Cephalaspis Lyellii*.

Comparing these enormous masses of conglomerate, arenaceous, and argillaceous rocks, and this included limestone, with the older Silurian series, we find the chief mineral distinction to be in the state of the iron which colours the rocks. Protoxide is common in the older series, peroxide is prevalent in the newer group. As in many other cases, the grey oxide series contain many, the red oxide rocks yield few remains of life. If life had been more abundant, the now

Family—*Echinoidea.*

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Palæchinus	1	...	...	1
Sub-Kingdom—ANNULOSA.				
Class—Annelida.				
Arabellites	2	...	...	2
Arenicolites	3	2	1	...
Conchicolites	1	...	1	...
Cornulites	1	...	1	1
Crossopodia	2	...	1	1
Cruziana	1	1	...	...
Dexolites	1	...	1	...
Haughtonia	1	1	...	...
Helminthites	1	...	1	1
Histioderma	1	1	...	...
Lumbricaria	2	...	2	...
Myrianites	2	...	2	...
Nemertites	1	...	1	...
Nereites	3	...	3	...
Palæochorda	3	...	3	...
Pyritonema	1	...	1	...
Salterella	1	...	1	...
Scolecoderma	2	2	...	...
Scolites	1	1	...	...
Serpulites	5	1	1	4
Spirorbis	1	...	...	1
Stella-scolites	1	...	1	...
Tentaculites	4	...	3	3
Trachyderma	4	...	2	2
Trichoides	1	...	1	..
25	46	9	27	15
Sub-Kingdom ANNULOSA.				
Class—Crustacea.				
Family—*Trilobita.*				
Acidaspis	13	...	8	7
Æglina	8	...	8	...
Agnostus	20	15	5	...
Amphion	3	...	3	...
Ampyx	9	1	7	1
Angelina	2	2	...	...
Anopolenus	3	3	...	...
Aptychopsis	3	...	3	...
Arionellus	1	1	...	...
Asaphus	17	3	16	...
Astacoderma	14	...	...	14
Barrandia	5	...	5	...
Bronteus	2	...	1	1
Calymene	16	...	14	5
Carausia	1	1	...	...
Cheirurus	9	1	9	1
Conocoryphe	21	21	...	...
Conophrys	1	1	...	..
Cybele	3	...	3	...
Cyphaspis	3	...	...	3
Cyphoniscus	1	...	1	...
Deiphon	1	...	...	1
Dikelocephalus	4	4	...	...
Dionide	1	1	1	...

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Encrinurus	4	...	3	2
Erinnys	1	1	...	...
Harpes	3	...	3	...
Holocephalina	2	2	...	...
Homalonotus	13	...	8	5
Illænopsis	1	...	1	...
Illænus	21	...	17	7
Lichapyge	1	1	...	...
Microdiscus	2	2	...	...
Nesuretus	4	4	...	...
Niobe	4	3	1	...
Lichas	13	...	6	8
Ogygia	9	3	9	...
Olenus	16	16	...	...
Paradoxides	5	5	...	...
Palæopyge	1	1	...	...
Parabolina	1	1	...	...
Parka	1	...	...	1
Phacops	28	...	22	6
Peltura	1	...	...	1
Proëtus	2	...	1	2
Placoparia	1	...	1	...
Platypeltis	1	1	...	...
Plutonia	1	1	...	...
Psilocephalus	2	2	...	...
Remopleurides	7	...	7	...
Salteria	2	...	2	...
Sphærexochus	2	...	2	1
Sphærophthalmus	1	1	...	...
Staurocephalus	5	...	5	1
Stygina	3	...	3	...
Tiresias	1	...	1	...
Trinucleus	12	...	12	1
57	332	98	188	68

Class—ENTOMOSTRACA and PHYLLOPODA.

Æchmina	2	...	...	2
Bairdia	4	...	3	1
Beyrichia	7	...	6	3
Caryocaris	1	...	1	...
Ceratiocaris	16	2	1	13
Cythere	7	...	5	2
Cypridina	1	...	...	1
Cytherellina	3	...	...	3
Dictyocaris	2	...	...	2
Discinocaris	1	...	1	...
Entomis	4	1	...	3
Hymenocaris	1	1	...	...
Kirkbya	1	...	...	1
Leperditia	4	4	...	1
Lingulocaris	1	1	...	...
Moorea	1	...	...	1
Myocaris	1	1	...	...
Necrogamarus	1	...	...	1
Peltocaris	3	...	3	...
Primitia	26	2	11	13
Thilipsura	3	...	...	3
21	90	12	31	50

Class—MEROSTOMATA.

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Eurypterus	10	...	...	10
Hemiaspis	6	...	...	6
Himantopterus	1	...	...	1
Neolimulus	1	...	...	1
Pterygotus	9	...	...	9
Slimonia	1	...	...	1
Stylonurus	2	...	...	2
7	30	...	...	30

Family—*Cirripedia.*

Turrilepas	1	...	...	1

SUB-KINGDOM—MOLLUSCOIDA.

Class—POLYZOA.

Berenicea	1	...	1	...
Cellepora	1	...	...	1
Ceriopora	4	...	...	4
Diastopora	3	...	...	2
Dictyonema	1	1	...	...
Discopora	3	...	...	3
Escharina	1	...	...	1
Fenestella	11	...	5	8
Glauconome	1	...	1	...
Heteropora	1	...	...	1
Intricaria	1	...	1	...
Polypora	1	...	...	1
Ptilodictya	8	...	7	5
Retepora	4	...	3	2
14	41	1	18	28

SUB-KINGDOM—MOLLUSCA (*Molluscoida*).

Class—BRACHIOPODA.

Acrotreta	1	...	1	...
Athyris	3	...	...	3
Atrypa	10	...	5	8
Chonetes	3	...	1	2
Crania	5	...	2	3
Cyrtia	1	...	...	1
Dinobolus	1	...	1	...
Discina	13	2	6	5
Eichwaldia	2	...	...	2
Kutorgina	1	1	...	...
Leptæna	42	...	23	17
Lingula	27	3	16	11
Lingulella	4	4	...	...
Meristella	9	...	3	7
Nucleospira	1	...	...	1
Obolella	6	4	2	...
Obolus	3	...	...	3
Orbiculoidea	2	...	...	2
Orthis	67	3	54	22
Orthisina	1	..	1	...
Pentamerus	7	...	3	7
Porambonites	1	...	1	...

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Encrinurus	4	...	3	2
Erinnys	1	1	...	...
Harpes	3	...	3	...
Holocephalina	2	2	...	...
Homalonotus	13	...	8	5
Illænopsis	1	...	1	...
Illænus	21	...	17	7
Lichapyge	1	1	...	...
Microdiscus	2	2	...	...
Nesuretus	4	4	...	...
Niobe	4	3	1	...
Lichas	13	...	6	8
Ogygia	9	3	9	...
Olenus	16	16	...	...
Paradoxides	5	5	...	...
Palæopyge	1	1	...	...
Parabolina	1	1	...	...
Parka	1	...	...	1
Phacops	28	...	22	6
Peltura	1	...	...	1
Proëtus	2	...	1	2
Placoparia	1	...	1	...
Platypeltis	1	1	...	...
Plutonia	1	1	...	...
Psilocephalus	2	2	...	...
Remopleurides	7	...	7	...
Salteria	2	...	2	...
Sphærexochus	2	...	2	1
Sphærophthalmus	1	1	...	...
Staurocephalus	5	...	5	1
Stygina	3	...	3	...
Tiresias	1	...	1	...
Trinucleus	12	...	12	1
57	332	98	188	68

Class—ENTOMOSTRACA and PHYLLOPODA.

Æchmina	2	...	...	2
Bairdia	4	...	3	1
Beyrichia	7	...	6	3
Caryocaris	1	...	1	...
Ceratiocaris	16	2	1	13
Cythere	7	...	5	2
Cypridina	1	...	...	1
Cytherellina	3	...	...	3
Dictyocaris	2	...	...	2
Discinocaris	1	...	1	...
Entomis	4	1	...	3
Hymenocaris	1	1	...	...
Kirkbya	1	...	...	1
Leperditia	4	4	...	1
Lingulocaris	1	1	...	...
Moorea	1	...	...	1
Myocaris	1	1	...	...
Necrogammarus	1	...	...	1
Peltocaris	3	...	3	...
Primitia	26	2	11	13
Thilipsura	3	...	...	3
21	90	12	31	50

Class—MEROSTOMATA.

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Eurypterus	10	...	...	10
Hemiaspis	6	...	...	6
Himantopterus	1	...	...	1
Neolimulus	1	...	...	1
Pterygotus	9	...	...	9
Slimonia	1	...	...	1
Stylonurus	2	...	...	2
7	30	...	...	30

Family—*Cirripedia.*

Turrilepas	1	...	...	1

SUB-KINGDOM—MOLLUSCOIDA.

Class—POLYZOA.

Berenicea	1	...	1	...
Cellepora	1	...	...	1
Ceriopora	4	...	...	4
Diastopora	3	...	...	2
Dictyonema	1	1	...	...
Discopora	3	...	...	3
Escharina	1	...	...	1
Fenestella	11	...	5	8
Glauconome	1	...	1	...
Heteropora	1	...	...	1
Intricaria	1	...	1	...
Polypora	1	...	...	1
Ptilodictya	8	...	7	5
Retepora	4	...	3	2
14	41	1	18	28

SUB-KINGDOM—MOLLUSCA (*Molluscoida*).

Class—BRACHIOPODA.

Acrotreta	1	...	1	...
Athyris	3	...	...	3
Atrypa	10	...	5	8
Chonetes	3	...	1	2
Crania	5	...	2	3
Cyrtia	1	...	...	1
Dinobolus	1	...	1	...
Discina	13	2	6	5
Eichwaldia	2	...	...	2
Kutorgina	1	1	...	...
Leptæna	42	...	23	17
Lingula	27	3	16	11
Lingulella	4	4	...	...
Meristella	9	...	3	7
Nucleospira	1	...	...	1
Obolella	6	4	2	...
Obolus	3	...	...	3
Orbiculoidea	2	...	...	2
Orthis	67	3	54	22
Orthisina	1	...	1	...
Pentamerus	7	...	3	7
Porambonites	1	...	1	...

The Old Red Sandstone of Britain admits of the following subdivisions: [1]—

2. UPPER.—Yellow and red sandstones, conglomerates, marls, &c., passing up *conformably* into the base of the Carboniferous system, and resting unconformably on the Lower Old Red Sandstone and every older formation. *Holoptychius, Pterichthys major*, &c.

1. LOWER.—Red sandstones, conglomerates, flagstones, and associated igneous rocks, passing in some places conformably down into Upper Silurian formations. *Dipterus, Coccosteus, Cephalaspis, Pterygotus*, &c.

It was on fossil evidence that Murchison relied when he proposed his "Middle" Old Red Sandstone group (*Caithness flags*). Nowhere or in no district can these three subdivisions be found together; "all," says Geikie, "that can be affirmed from stratigraphical evidence in any Old Red Sandstone district in Britain, is that a great physical and palæontological break can generally be traced in the Old Red Sandstone, *dividing it into two* completely distinct series." Mr. Geikie's work in the centre and south of Scotland has thus shown the Old Red Sandstone to consist of two great divisions. As stated, a similar condition occurs in the south-west of Ireland. The three groups do not occur in any one continuous section, nor are they met with together in the same region.

Through a knowledge of "these *venerable deposits* we obtain some of the earliest traces of land on the surface of the globe. They bring before us portions of the Palæozoic continent which preceded our modern Europe." [2]

Lower Old Red Sandstone.

In his memoir on the Old Red Sandstone of Western Europe, Professor A. Geikie [3] traces the series of changes in the physical geography of Western Europe which took place between the close of the Upper Silurian and the commencement of the Carboniferous period.

Mr. Godwin Austen was the first physicist who drew attention to the fact that the land of older Palæozoic age previous to the deposition of the "Old Red" lay mostly beyond the present area of Europe, then covered by the Silurian sea, probably to the north and north-west.[4] The crystalline axis of Scandinavia, prolonged into the north-west of Scotland down the chain of the Hebrides, remains as a fragment of this ancient Silurian land, which must have occupied a wide area in that direction, as may be inferred from the character and thickness of the Silurian strata. Geikie estimates the mean depth of

[1] *Vide* Professor Geikie "On the Old Red Sandstone of Western Europe," in the Trans. Roy. Soc. Edin., vol. xxviii., 1878.

[2] Sir A. C. Ramsay, in Quart. Journ. Geol. Soc., vol. xxvii., has discussed the question of the occurrence of red formations with the existence of salt lakes, &c. He draws attention to the presence of land-plants, footprints of amphibia, &c., and the stunted condition of marine mollusca or their total absence.

[3] *Loc. cit.*

[4] For the extension eastwards of the Silurian rocks as far as Ware, north of London, see Etheridge, Pop. Sci. Rev., vol. iii. 1879, pp. 279–296.

Genera.	No. of Species.	Cambrian.	Lower Silurian.	Upper Silurian.
Loxonema	3	...	1	2
Macrocheilus	2	...	1	1
Murchisonia	24	...	16	8
Natica	1	...	...	1
Ophileta	2	...	2	...
Patella	1	...	1	...
Platyschisma	3	...	2	3
Pleurotomaria	9	...	5	4
Raphistoma	5	...	5	2
Trochus	3	...	2	2
Turbo	2	...	2	1
Trochonema	4	...	4	2
18	107	...	67	54

Class—HETEROPODA.

Bellerophon	22	5	14	10
Ecculiomphalus	3	...	2	2
Maclurea	5	...	5	...
3	30	5	21	12

Class—CEPHALOPODA.

Actinoceras	3	...	...	3
Ascoceras	1	...	...	1
Cyrtoceras	7	1	6	1
Endoceras	1	...	1	...
Exosiphonites	2	...	...	2
Koleoceras	3	...	3	...
Lituites	9	...	5	5
Oncoceras	1	...	1	...
Orthoceras	71	1	45	35
Phragmoceras	6	...	1	6
Piloceras	1	...	1	...
Poterioceras	1	...	1	...
Tretoceras	2	...	1	1
Trocholites	1	...	1	...
14	109	2	66	54

SUB-KINGDOM—VERTEBRATA.

Class—PISCES.

Auchenaspis	2	...	...	2
Cephalaspis	3	...	...	3
Eukeraspis	2	...	...	2
Onchus	2	...	...	2
Plectrodus	2	...	...	2
Pteraspis	2	...	...	2
Scaphodus	1	...	...	1
Sphagodus	1	...	...	1
Thelodus	1	...	...	1
Thyestes	1	...	...	1
Scaphaspis	2	...	...	2
11	19	...	...	19

Areas of Basins.	Short Reference Names Proposed to Designate them.
1. "A wide region embracing all the Old Red Sandstone to the north of the Grampian range. Its southern and western border skirts the northern base of the Highland mountains, running up here and there in long fjords or bays. It includes the whole of the Orkney Islands, while its northern margin may be traced in the Shetland group." It is typically developed in Caithness, and estimated at 16,000 feet thick.[1]	Lake Orcadie.
2. "The centre valley of Scotland, between the range of the Highland mountains on the north, and that of the Silurian pastoral uplands of the southern counties. This basin was probably prolonged across the Firth of Clyde into the North of Ireland."	Lake Caledonia, or the Mid-Scottish Basin.
3. "A portion of the South-East of Scotland and the North of England, extending from near St. Abb's Head south-westward along the basin of the Silurian Hills to the head of Liddesdale, and including the area of the Cheviot Hills."	Lake Cheviot.
4. "The Old Red Sandstone region of Wales, bounded on the north and west by the Cambrian and Silurian rising grounds, but its eastern and southern extension obscured by later formations."	The Welsh Lake.
5. "A district in the north of Argyleshire, extending from the south-east of Mull to Loch Awe, and perhaps northward up *the line of the Great Glen*." —*A. Geikie, loc. cit.*	Lake of Lorn.

Lake Orcadie.—The most northerly of these basins, or Lake Orcadie, presents marked peculiarities, showing that it probably remained separated from the more southern areas, although a communication may have been occasionally open between them, perhaps by the ancient hollow of the Great Glen (Caledonian Canal). In some cases the margins of these basins can be laid down for many miles with accuracy.

Under the name "*Lake Orcadie*" may be united all the Old Red Sandstone lying to the north of the Scottish Highlands. Petrographical and palæontological evidence shows that this great basin was an area of deposit distinct from that of Central Scotland, or Lake Caledonia. Examination shows that "little more than its southern

[1] The thickness of the series in Caithness is upwards of 16,000 feet. The Caithness flagstones belong to the Lower Old Red Sandstone, and there is no middle division or Middle Old Red. Many fish are common to both the Caithness and Arbroath flags. *Acanthodes* and *Diplacanthus* occur in both, and *Parexus incurvus* occurs both in the northern and southern basin. "The admitted *palæontological distinctions* are probably not greater than the *lithological differences* between the strata of the two regions would account for, or than the contrast between the ichthyic faunas of contiguous water-basins at the present time."

and western margin can be seen on the mainland (Caithness and Sutherland), but taking this part in connection with the Orkney and Shetland Islands to the north, all once connected with the mainland, we may thence form some notion of the area of this old lake, and the changes in physical geography it has suffered." What is now an archipelago embracing the Orkneys and the Shetland Islands was in moderately recent times dry land, to say nothing of the extension of the northern coasts of the two counties above named still farther northwards, or into the North Atlantic.

"The marginal belt of the ancient lacustrine area is marked by thick conglomerates, which lie unconformably upon the worn edges of the metamorphic rocks. These marginal conglomerates, therefore, indicate the shore-lines of the old lake, and may still be traced. Towards the north, Lake Orcadie stretched over the site of Caithness and the whole of the Orkney Islands."

Geographical Districts in Lake Orcadie.—Professor Geikie has again divided the area included under the name of Lake Orcadie into four geographical districts :—

1. *Caithness and Sutherland.*
2. *The Orkneys.*
3. *The Shetland Islands.*
4. *The Basin of the Northern Firths.*

A. Caithness and Sutherland.—The Old Red Sandstone occupying this district in Lake Orcadie is estimated at 16,000 feet in thickness.

After describing the structure of the Old Red Sandstone and sections in the Lake Orcadie, the author relates the *order of succession among the strata*, showing the lithological and palæontological characters of the Caithness flagstones. The following table shows the subdivisions made out, their thicknesses, and the localities where they are best seen. It is important to study in detail this table of Professor Geikie's, it being essential to the geological history of the rocks under consideration.[1]

[1] The student should carefully trace these basins on the geological map of Scotland, and also the Cheviot and Welsh lakes on that of England and Wales.

TABLE XVIII.—*Showing the Order, Thickness, and Typical Localities of the Leading Subdivisions of the Old Red Sandstones of Caithness in Descending Order.*

Subdivisions.	Strata.	Thickness in Feet.	Localities where the Rocks Occur.
John O'Groat's Sandstone and Flagstone Group.	9. Red Sandstone, with occasional bands of flagstone, thin impure limestone, and shale.	2000	John O'Groat's House on the shore.
Huna Flagstone Group.	8. Flagstone, shales, and thin impure limestone.	1000	Shore at Huna.
Gill's Bay Sandstone.	7. False-bedded red sandstones.	400	Gill's Bay on Pentland Firth.
Thurso or Northern Flagstone Group.	6. Dark-grey and cream-coloured flagstones, grey and blue shales and thin limestones, some beds strongly bituminous. This group is more fissile, shaly, and calcareous than No. 5.	5000	Coast-line of Caithness from Reay to Dunnet Bay, and from Brough to Gill's Bay, Stroma, and the Orkney Islands.
Wick and Lybster or Eastern Flagstone Group.	5. Dark-grey flagstones, often thick-bedded, thin shales and limestone bands, passing into red shales and sandstones.	5000	Coast on either side of Wick, and inland to Banniskirk.
Lower Red Sandy and Conglomerate Groups.	4. Dark-red sandstones and occasional red shales and bands of fine conglomerate, passing inland into conglomeratic sandstone.	2000	Coast south and north of Berriedale Water, Sarclet, Braemore, Morven, &c.
Do.	3. Brecciated conglomerate.	300	Coast at Badbea.
Do.	2. Dull chocolate-red sandstones, and sandy shales or clays.	450	Berriedale Water around Braemore.
Do.	1. Coarse basement conglomerate.	50	Berriedale Water below Braemore, and mouth of Ousedale Burn.
		16,200	

All these nine subdivisions are elaborately described in Professor Geikie's Memoir, to which we must refer the student.

The fifth division, *or the Wick and Lybster Flagstones*, is the lowest or first that occurs in ascending order in which terrestrial plants

and fishes fairly commence in various horizons. The genus *Psilophyton* predominates, with large stems of *Caulopteris Peachii*, *Pinnularia*, and coniferous remains, referred to *Araucarioxylon*. No true marine plants have yet occurred in the Caithness flagstones.

Fragments of large Crustacea, probably *Pterygotus*, occur at Kilmster; the small phyllopod, *Estheria membranacea*, is found both at Reiss and Wick. With relation to the Caithness fishes, *Dipterus macrolepidotus* has the widest range; it appears low down in division 4 at Berriedale, and ranges up to the upper part of division 8, or in the Huna beds. *Diplopterus borealis* and *Osteolepis macrolepidotus* have also a wide vertical range. Again, *Acanthodes*, *Diplacanthus*, and *Parexus*, found in the Forfarshire flagstones, occur only in Caithness in the sixth division, or the Thurso group; whereas the *Osteolepis microlepidotus*, so characteristic of the Forfarshire beds, has not been observed in the Wick flagstones.

Fauna and Flora: The Thurso and Reay Flagstones.—These flagstones and bituminous limestones yield a large fish fauna, and the characteristic distinction of the Thurso group is *the first appearance of Acanthodian fishes*, none of this sub-order having appeared in the lower group.

Three species of *Acanthodes* have occurred in the flagstone.

Three species of *Cheiracanthus* occur at Holburn Head and east of Thurso.

Three species of *Diplacanthus* have been found at the Hill of Forss.

Osteolepis microlepidotus is most abundant in the Thurso group, mingled with *Acanthodes* and *Cheiracanthus;* it is the characteristic fish of the flagstones of commerce. *Glyptolepis elegans* abounds, *Parexus incurvus* is rare, and the Phyllopod *Estheria membranacea* crowds the surfaces of the shales and flagstones to the east of Thurso. Plant-remains abound in many parts of the Thurso flagstone group, viz., *Lycopodites Milleri* (Salt.), *Psilophyton robusticus*, and *Caulopteris Peachii*.

The blue flagstones and impure limestones of the *uppermost* or *John O'Groat's Red Sandstones* contain *Acanthodes Peachii*, *Dipterus* sp., *Pterichthys Dicki*, *Tristichopteris alatus*, and *Glyptolepis leptopterus*. The plants that occur have a general resemblance to those of pre-Carboniferous time in Canada. *Lepidodendron Gaspianum*, "remains allied to *Cyclostigma densifolium; Cyclopteris* like *C. Brownii*, and a Calamite resembling *C. transitionis*."[1]

B. The Orkney Islands.—It is impossible to omit noticing in outline some of the more prominent features connected with the palæontology of these islands, both these and the Shetland Islands forming part of the Lake Orcadie. The rocks of the Orkneys consist of the flagstones and sandstones of the Caithness flag series. The upper part of the great Caithness series stretches across the Pentland Firth and reappears in South Ronaldshay.

[1] Dawson on the "Fossil Plants of the Devonian Rocks of Canada" (Mem. Geol. Surv. of Canada, 1871.)

FAUNA.—The dark, hard, fissile, bituminous bands are charged with fossil fish. The plant-remains are those found in the Thurso and Upper Caithness groups. *Estheria membranacea* is quite as abundant at *Kirkwall* as at *Thurso*, thus corroborating by fossil evidence the theory that the Orkney rocks belong to the upper part of the Caithness series. The Acanthodean fishes are *Cheiracanthus*, *Diplacanthus*, and *Cheirolepis*, *Coccosteus*, *Asterolepis asmusii*, *Diplopterus*, *Osteolepis*, and *Dipterus macrolepidotus*. A more intimate connection still between the flagstones of the Orkneys and the fish-bearing strata of the Moray Firth is furnished by the occurrence in both areas of *Pterichthys cancriformis* and *P. Milleri*.

C. The Shetland Islands.—Forty-five miles north-east of the Orkneys rises the bold southern promontory of Sumberg Head. The cliffs are those of Orkney and Caithness, suggesting that the whole form parts of one continuous area; but here is reached the northern or north-eastern limits of the Lake Orcadie; only a narrow strip occurring on the south-east side of the Shetland group.[1] The main mass of the islands consists of crystalline rocks (metamorphosed Silurian, serpentine, quartz porphyries, &c., &c.), with limestones in the centre of the main island. Organic remains in the Shetlands are not uniformly distributed; no remains of fish have been detected. *Estheria* occurs in the flaggy beds near Lerwick, and plant-remains of doubtful affinities have been found.[2]

D. Basin of the Northern Firths.—Within this area and under this name is included all the Old Red Sandstone lying on the mainland of Scotland to the north of the Grampian chain (*except Caithness and the north of Sutherlandshire*). It probably originally formed one great basin of deposit or a connected series of *minor basins*. The deposits are different from those of the Caithness or Lake Orcadie basin, presenting strongly marked lithological distinctions as compared with those of the Caithness and Orkney regions. *The description of the "outliers" in this basin, the south coast of Lake Orcadie from Buckie to the Spey, from the Spey to the Nairn, from the Nairn to Inverness, and Loch Ness to Sutherlandshire*, must be read to have any idea of the research needed to write the physical history of the distribution of the Old Red Sandstone of the Northern Firths.

FAUNA.—The distribution of fish life through the Lower Old Red Sandstone of the Gamrie beds is clearly determined by the occurrence of *Cheiracanthus Murchisoni*, *Diplacanthus longispinus*, *Cheirolepis uragus*, *Diplopterus affinis*, *Glyptolepis elegans*, *Osteolepis major*, *O. arenatus*, *Pterichthys Milleri*, and *P. oblongus*, the whole of which are Lower Old Red Sandstone. The Tynet Burn and Dipple beds have yielded the following species of Lower Old Red fish: *Acanthodes pusilus*, *Cheiracanthus microlepidotus*, *C. Murchisoni*, *Diplacanthus striatus*, *D. striatulus*, *Glyptolepis leptopterus*, and *Osteolepis major*. In the beds between the Spey and the Nairn the following species have been

[1] *Vide* Map of the Shetland Isles.

[2] For the structure of the Shetlands, see Geikie, *loc. cit.*, pp. 414–421. Murchison, Q. Jour. Geol. Soc., vol. xv. Hooker, *ibid.*, vol. ix., &c.

collected, viz. *Pterichthys latus, P. Milleri, P. productus, P. cornutus, P. oblongus, Coccosteus maximus, C. oblongus, Cheiracanthus microlepidotus, Diplacanthus striatulus, D. longispinus, Cheirolepis Cummingiæ, C. curtus, Osteolepis major, Diplopterus macrocephalus, Glyptolepis leptopterus,* and *G. microlepidotus.*[1]

Eighteen genera and 61 species of fish are known to occur in the Lower Old Red Sandstone of the North of Scotland, or in Lake Orcadie; and of these 61, 47 occur on the north side of Moray Firth Fifteen genera and 35 species occur in the Orkney Islands.

Lake Caledonia.—In the central basin or Lake Caledonia, the twofold division of the Old Red Sandstone is typically seen; the lower series of deposits attain a maximum depth of 20,000 feet. These strata everywhere show traces of having been deposited in shallow water. "The accumulation of so great a thickness can only be explained on the supposition that the earth movements which at first elevated the Silurian sea-floor into land, *enclosing separate basins*, continued through subsidence to deepen these basins, until eventually enormous masses of sediment which had accumulated *pro rata* with subsidence, had filled or gathered in them."

Associated Volcanic Rocks.—"One of the most marked physical and lithological features within the central Scottish basin is the occurrence in it of prodigious masses of interbedded volcanic rocks. These consist of porphyritic lavas, felsites, and tuffs, more than 6000 feet thick, forming important chains of hills, as in the Pentland, Ochil, and Sidlaw ranges. They lie several thousand feet above the base of the system, and are here and there regularly interstratified with the ordinary sedimentary strata." "They point," says Mr. Geikie, "to the outburst of numerous volcanic vents along the lake or inland sea in which the Lower Old Red Sandstone of central Scotland was laid down."

Fauna and Flora.—Few fossils occur in Lake Caledonia; only in the Forfarshire (Arbroath) flagstones have any been met with, and these are chiefly fish and Crustaceans, *Pterygoti, Eurypteri, Stylonuri,* and *Phyllopoda.* The Arbroath flags have yielded 17 species of fish belonging to the sub-orders *Acanthodidæ* and *Ostracastei, Acanthodes Mitchelli, Diplacanthus gracilis, Climatius scutiger, C. reticulatus, C. uncinatus, Parexus incurvus, Euthacanthus* (1 species), *Cephalaspis Lyelli,* and *Pteraspis Mitchelli.* We have seen that 61 species of fish have been obtained from the Old Red Sandstone of the north of Scotland, and from the lower division.[2] In the flagstones land-plants abound, but are difficult to determine. *Psilophyton, Lepidodendron, Stigmaria, Calamites,* and *Cyclopteris* have been obtained.

[1] This first part, devoted only to Lake Orcadie, occupies 108 quarto pages; full descriptions of Lake Caledonia, Lake Cheviot, the Welsh Lake, and Lake Lorne have yet to come (Professor A. Geikie on the O. R. S. of Western Europe, Roy. Soc. Edin., 1878, vol. xxviii.)

[2] The following genera are specially characteristic: *Cheiracanthus, Asterolepis, Cheirolepis, Coccosteus, Acanthodes, Diplacanthus, Diplopterus, Dipterus, Glyptolepis, Osteolepis,* and *Pterichthys.*

Land-plants are abundant in the higher groups of the flagstones; in them occur forms of *Psilophyton*, *Lepidodendron*, *Stigmaria*, *Sigillaria*, *Calamites*, and *Cyclopteris*, &c.

"In the Shetland Islands there are traces of contemporaneous volcanic rocks; these, with the exception of two examples in the region of the Moray Firth, are the only known instances of volcanic action in the Lower Old Red Sandstone of Lake Orcadie. In the other two Scottish basins, those of the Cheviot Hills and of Lorne, volcanic action, long continued and vigorous, produced thick piles of lava like those of Lake Caledonia."[1]

Upper Old Red Sandstone.

Scotland.—Yellow and white sandstones, red clays and marls, with breccias and conglomerates, range below the Carboniferous system. Wherever "the stratigraphical relations of these strata can be distinctly traced, they lie conformably upon every formation older than themselves, including even the Old Red Sandstone; while, on the other hand, they pass up conformably to the Carboniferous rocks above. They contain well-marked genera of fishes allying it with the Lower Old Red Sandstone, such as *Pterichthys major* and *Holoptychius nobilissimus*, which occur in one locality, Dura Den in Fife, associated with *Holoptychius Andersoni*, *Glyptopomus*, *Glyptolæmus*, and *Phaneropleuron;* otherwise the Upper Old Red Sandstone of Scotland is remarkably barren of organic remains." "In the North of Scotland, on the Lowlands bordering the Moray Firth, and again in the Island of Hoy, one of the Orkney group, yellow and red sandstones, sometimes containing characteristic Upper Old Red Sandstone fishes, are found *lying unconformably* upon the older Caithness flags; thus the same relation occurs in these northern tracts between the two divisions of the system as in the central counties."

Ireland.—The Old Red Sandstone is greatly developed in the south and south-west of Ireland, and overlies the "Glengariff grits," which are about 10,000 feet thick. These grits may represent the Lower Old Red Sandstone of Scotland. They are unconformably overlaid by the "Old Red Sandstone" of the Irish geologists, which may be the equivalent of the Scottish Upper Old Red. In Ireland this Upper Old Red consists of a lower thick series of green, purple, and red grits and slates, and an upper and thinner group of yellowish or grey flagstones. *Bothriolepis*, *Pterichthys*, and *Glyptolepis* occur with the fresh-water shell *Anodonta Jukesii*, associated with ferns and other land-plants. The ferns are *Palæopteris*, and *Sphenopteris*, with the higher land-plants *Sagenaria*, *Knorria*, and *Cyclostigma*. The Crustaceans *Belinurus* and *Pterygotus* occur in the same beds as the fish above named.

[1] Geikie, *loc. cit.*

Devonian Rocks.

We are indebted to Sir H. T. de la Beche for the first clear views of the succession of these beds in North Devon. The country is greatly contorted throughout its entire range, the anticlinal and synclinal folds run chiefly from east to west, and the faults are mostly downthrows to the east. Professor Phillips advantageously arranged the great North Devon series in the following six groups, reading upwards:—

North Devonian Type.

6. UPPERMOST GROUP OF PILTON.—A series of flaggy sandstones and shales, with interrupted and nodular deposits of limestone, containing the remains of fishes analogous to those found in the lowest part of the mountain limestone series, with which it might without much inconvenience be classed. The group immediately below undoubtedly *belongs to the Old Red series*, and is finely exhibited at Pickwell Down.
5. MORTEHOE GROUP.—Purple and grey slaty or schistose series, with interstratified gritstones (slaty cleavage). No fossils.
4. ILFRACOMBE GROUP.—*Grey* argillaceous series, with limestone bands containing numerous corals and mollusca (slaty cleavage).
3. MARTINHOE GROUP.—*Red*, claret-coloured, grey, and brown grits, with schists, &c. (slaty cleavage). No fossils.
2. LYNTON GROUP.—(1000 feet thick), mostly *grey* laminated grits, slates, and shales, with numerous fossils, and occurring in partially calcareous bands (slaty cleavage).
1. FORELAND GROUP.—*Red*, grey, and claret-coloured grits and shales (with slaty cleavage). No fossils; base not seen.

Passing from North to South Devon, we cross wide regions of Carboniferous rocks (composed of grits, thin-bedded sandstones, and shales totally void of coals or fossils, either plants or mollusca, &c.) Granitic and porphyritic eruptions have much dislocated the strata, and it becomes difficult to draw lines of exact contemporaneity with the rocks on the opposite sides even of this one county.[1] The following appeared to Professor Phillips to be the best section; it occurs in Plymouth Sound, and with a southerly dip:—

South Devonian Type.

Group of *red* sandstone and shales, with grey and purple shales (traversed more or less by slaty cleavage). In the grey shales and slates, Corals, Encrinites, and Brachiopoda are frequent.

Group of *grey* schists and subcalcareous beds, interstratified with what seem to be ash beds (thrown out by ancient volcanoes), and recomposed traps. Fossils nearly as in the strata above.

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[1] See on these points: De la Beche (Memoirs of Geological Survey, vol. i.), On the Formation of the Rocks of South Wales and South-Western England; also Ramsay on the Denudation of South Wales and the Adjacent Counties of England (Mem. Geol. Surv., vol. i. pp. 297-335. 1846). Geological Report on Cornwall, Devon, and West Somerset, 1839. Phillips' Palæozoic Fossils of Devon and Cornwall, 1841.

Group of limestones, abundant at Plymouth, Torquay, &c. It is quite irregular, sometimes like huge coral reefs; in other places divided by shale partings, as at Ilfracombe, and toward the west thinning off to subcalcareous shales. Abundance of Corals, Brachiopoda, Gasteropoda, Cephalopoda, &c. Very slight traces of fishes at Looe, Polperro, &c.

Group of purple slaty rocks, some ash beds; the original lamination traceable. No fossils observed.

If we class, as appears most advisable, the Plymouth limestone with that of Ilfracombe, we shall find the higher beds of South Devon by no means physically unlike the lower beds of North Devon. On the whole. the red element is diminished, animal life being more widely diffused. The Plymouth, Torquay, and Newton Bushel limestones contain many Eifel species, and may be regarded as typical of the Middle Devonian series.

Although the actual passage of these strata into rocks of older date has never been seen, their passage upwards into the Carboniferous series can be clearly determined in North Devon. The total thickness of the Devonian rocks has been stated to be about 10,000 feet, of the Old Red Sandstone 16,000 feet. The faunal value of the true Devonian is about 150 genera and 450 species; the true Old Red of Scotland yields 50 genera and 125 species, chiefly fishes.

Extension of the Upper Devonian Rocks of North Devon to the Meridian of London.—The possible existence and extension of the coal measures and older rocks beneath the south-eastern part of England, either from the south-western part of England or from the Continent, has long engaged the attention of physical geologists. Speculative as these views seemed to be, they but foreshadowed what is now realised. The continuity of the Palæozoic rocks, from the Belgian and German areas, under the German Ocean, and also the French deposits under the English Channel from the north-east of France, has now become an acknowledged certainty. We now know that both the Upper Silurian and Upper Devonian rocks occur as far east from North Devon and Wales as London; the former at Ware in Hertfordshire, and the latter in London, and at Turnford, south of Ware. Both these rocks were discovered in seeking for a supply of pure water for the metropolis. The *Upper Devonian* at Turnford was determined at the depth of 820 feet; at Tottenham Court Road,[1] 980 feet; the *Upper Silurian* at Ware at 700 feet; the *Wenlock shale* here yielding (from the "cores") no less than 24 genera and 33 species of fossils representing 8 classes.[2]

The true Upper Devonian beds of North Devon are developed in the area south of and above the Upper Old Red Sandstone (*or Old Red Sandstone*) of Pickwell Down, viz., at Baggy Point, or the Baggy series, in which are the Marwood and Sloly beds. The Croyde

[1] Messrs. Meux's Brewery.

[2] See Pop. Sci. Rev., vol. iii. 1879, pp. 279–296, by R. Etheridge, for description and section illustrating the physical strata of the area.

series, so finely shown along the bay (Croyde Bay), are succeeded by the highest members, or the Pilton and Barnstaple beds; these last pass insensibly or graduate upwards into the Bideford beds or base of the Carboniferous system, as exposed at Venn, Swimbridge, &c., and appear to represent the Upper Old Red Sandstone of the rest of Britain. The importance of this group of Upper Devonian rocks cannot be over-estimated, whether we claim them as Lower Carboniferous or Upper Devonian. They contain a few land-plants and some marine Carboniferous Mollusca, but unlike any part of the Upper Old Red and transitional series into the Carboniferous system, as it occurs all round the Welsh coalfield or the Bristol area, where it is well seen in the Avon section. Without any intermediate marine fauna of a peculiar type. the Lower Limestone shales rest at once upon the red and yellow sandy beds of the Old Red proper, which here contain many pebbles. The change in mineral or petrological character, accompanied by the introduction of a marine fauna allied to that of Belgium and France, in the calcareous and slaty sediments in North Devon, which overlie the barren Pickwell Down or Old Red Sandstones, has no parallel in the British Islands; the nearest approach to the North Devon beds being the Coomhola series of the South of Ireland. Sedgwick and Murchison placed the Marwood beds as the uppermost group of their Devonian system, above which are the Croyde fossiliferous slates, or between the Pilton and Baggy or Marwood beds.

The following table embraces all the subdivisions of the North Devon rocks, with the species in each group from the Coal Measures to the Lower Devonian of the Lynton area, in descending order and in the typical localities:—

TABLE XIX.—*Devonian Rocks of North Devon.*

	Horizons	Physical Characters.	Species Occurring in the Stratigraphical Divisions.
CARBONIFEROUS.	COAL MEASURES.	A series of grits, shales, and sandstones, extending for thirty miles, but possessing no coal south of Bideford, where there occurs a thin and impure culm or anthracitiferous coal.	*Asterophyllites flosa, Calamites arenaceus, C. undulatus, Cyperites bicarinata, Neuropteris cordata, N. gigantea, N. heterophylla, N. Looshii, Alethopteris lonchitica, Pecopteris coconia, Sphænopteris acuta, S. latifolia, Stigmaria ficoides, Sigillaria, Sphenophyllum, Sternbergia, Lepidodendron, Anthracosia* sp., *Goniatites Listeri, Cœlacanthus,* and *Elonichthys.*
	CODDON HILL BEDS. MILLSTONE GRIT.	Hard, fine-grained, pale-yellow, or nearly white grits, in places red or brown.	
	LIMESTONES AND SHALES.	Beds of impure limestone and shales evenly bedded; the limestones are earthy, compact, and in places argillaceous.	*Posidonomya Becheri,* and *vars. P. lateralis, P. membranacea,* and *P. tuberculata, Goniatites sphæricus, G. mixolobus, G. spiralis,* and *Orthoceras cylindraceum.*
UPPER DEVONIAN.	BARNSTAPLE BEDS.	Dark schists, resting on light-coloured grey slates with calcareous nodules.	*Spirifera laminosa, S. cuspidatus, S. ovalis, S. bisulcatus, Streptorhynchus crenistria, Chonetes Hardrensis, Athyris Roysii, Bellerophon decussatus, Productus costatus, P. Martini, Orthis Michelini, Venus parallela, Phillipsia seminifera,* and *Cyathocrinus distans.*
	PILTON BEDS.	Purple and grey slates, with thin intermittent bands of limestone, highly fossiliferous.	*Cyathocrinus pinnatus, C. variabilis, Actinocrinus, Potereocrinus, Rhodocrinus, Protaster, Palæaster, Petraia celtica, Fenestella antiqua, Glauconome bipinnata, Avicula damnoniensis, Strophalosia caperata, S. productoides, Spirifera disjuncta, Productus prælongus, Orthis interlineata, Athyris concentrica, Chonetes Hardrensis, Spirifera Urii, Streptorhynchus crenistria, Strophomena analoga, Curtonotus, Sanguinolites, Euomphalus serpens, Phacops latifrons.*
	BRAUNTON BEDS.	... ...	... ...

	Horizons.	Physical Characters.	Species Occurring in the Stratigraphical Dividions.
UPPER DEVONIAN.	CROYDE BEDS.	Fine grey and brown slates, cleaved and jointed.	*Phacops latifrons*, *Athyris concentrica*.
	BAGGY BEDS, including *Georgeham*, *Marwood*, and Sloly, &c., &c.	Light-grey and olive-green slates, with bands of hard grit, and calcareo-ferruginous beds with Cucullæa. Below these occur yellowish and greenish flags and shales, passing downwards into purple sandy shales and grits (Upcot beds).	*Phacops latifrons*, *Trimerocephalus* (*Phacops*) *lævis*, *Petraia celtica*, *P. pleuriradialis*, *Fistulipora cribrosa*, *Ceriopora gracilis*, *Glauconome bipinnata*, *Fenestella antiqua*, *Pentremites ovalis*, *Cyathocrinus macrodactylus*, *C. geometricus*, *Lingula squamiformes va Mola*, *Discina nitida*. *Terebratula sacculus*, *T. elongata*, *Athyris concentrica*, *Spirifera disjuncta*, *S. Urii*, *S. cristata* vel *octoplicata*, *S. microgamma*, *S. decussata*, *S. obliterata*, *S. mesomala*, *S. megaloba*, *Orthis plicata*, *O. parallela*, *O. interlineata*, *Rhynchonella pleurodon*, *R. laticosta*, *Stropholosia productoides*, *S. scabriculus*, *Productus prælongus*, *P. longispinus*, *Chonetes Hardrensis*, *Streptorhynchus crenistria*, *Cucullæa trapezium*, *C. Hardingii*, *Ctenodonta antiqua*, *Avicula damnoniensis*, *Aviculopecten granulosus*, *A. transversus*, *Pterinæa rudis*, *Acroculia vetusta*, *Euomphalus serpens*, *Pleurotomarea cancellata*, *P. gracilis*, *Loxonema reticulata*, *L. rugifera*, *Macrocheilus neglectus*, *Bellerophon globatus*, *B. bisulcatus*, *Stigmaria*, *Rhodea*, and *Knorria*.
	White and yellow slates at the base (plant beds).		
	BRUSHFORD BEDS = Marwood.		
	PLANT BEDS at base.		
	VENTION SERIES = place of the Petherwin beds.	Thin-bedded arenaceous beds and slates immediately above the Pickwell Down sandstones, passage beds into the Boggy series.	No fossil remains here.
	PICKWELL DOWN SANDSTONES.	Red, purple, green, grey, and brown sandstones, and massive grits (Upper Old Red Sandstone).	No organic remains.
MIDDLE DEVONIAN.	MORTE HOE.	Pale-grey glossy slates with quartz veins, nearly vertical.	No organic remains.
	ROCKHAM BAY. LEE.	Pale-grey slates with veins of quartz.	No organic remains.

	Horizons.	Physical Characters.	Species Occurring in the Stratigraphical Divisions.
MIDDLE DEVONIAN.	ILFRACOMBE BEDS.	Slates, shales, and impure limestones. Variable beds of grey slates and thin grits, containing numerous bands of blue earthy impure limestone, "*Stringocephalus limestone;*" the limestones occur in lenticular masses and abound in places with Corals and Polyzoa.	*Cyathophyllum cæspitosum, C. obtortum, C. æquiseptum, C. helianthoides, Cystiphyllum damnoniense, C. vesiculosum, Favosites cervicornis, F. dubia, Heliophyllum Hallii, Pachyphyllum devoniense, Cyathocrinus macrodactylus, C. variabilis, Tentaculites scalaris, Ceriopora similis, Fenestella antiqua, F. arthritica, Retepora repisteria, Phacops (trimerocephalus) lævis, Rensseleria stringiceps, Merista plebeia, Spirifera canalifera, S. disjuncta, Rhynchonella euboides, Strophomena rhomboidalis, S. analoga, Orthoceras cylindraceum, Loxonema sp. natica, Hallia Pengellyi, Heliolites porosa, Michelinia, Petraia bina? P. pleuriadialis, Hemitrypa oculata, Cyrtoceras.*
	HELSBOROUGH.	... ...	Poor in fossils.
	HAGGINGTON BEDS. TENTACULITE BEDS at the base. RILLAGE BEDS.	Same as Ilfracombe.	*Stromatopora concentrica, Cyathophyllum æquiseptum, C. Bolonense, Favosites cervicornis, Tentaculites scalaris, Atrypa desquamata, A. reticularis, A. aspera, Cyrtina heteroclyta, Merista plebeia, Orthis interlineata, O. striatula, Rensseleria stringiceps, Rhynchonella pleurodon, R. pugnus, Spirifera curvata, S. disjuncta, S. nuda, S. speciosa, Stringocephalus Burtini, Streptorhynchus crenistria, Acroculia vetusta, Euomphalus serpens, Conularia Goniatites spiralis, Athyris concentrica, Orthis crenistria, Cyathocrinus macrodactylus, Strophomena rhomboidalis, Phacops lævis, Cyrtina heteroclyta, Schizodus deltoideus?, Mytilus damnoniensis.*
	WIDMOUTH BEDS.	Grey argillaceous grits and impure limestones.	*Tentaculites scalaris, Favosites cervicornis.*

	Horizons.	Physical Characters.	Species Occurring in the Stratigraphical Divisions.
MIDDLE DEVONIAN.	WATERMOUTH BEDS.	Hard siliceous beds with *Stringocephalus Burtini*, *Phacops lævis*, and impure limestones at the base.	*Favosites cervicornis*, *Tentaculites scalaris*, *Spirifera disjuncta*, *Stringocephalus Burtini*, *Trimerocephalus* (*Phacops*) *lævis*, *Atrypa reticularis*, *A. aspera*.
	COMBE MARTIN AND COMBE MARTIN BAY BEDS.	Beds of limestones and shales, red sandstones and dark-grey slates at the base, with Stringocephalus.	*Favosites cervicornis*, *Fenestella*, *Phacops* (*trimerocephalus*) *lævis*, *Stringocephalus Burtini*.
	HANGMAN AND TRENTISHOE GRITS, &c.	Hard, fine-grained, red, purple, and grey grits, with bands of slate rising from below the Ilfracombe slate at Combe Martin Bay.	*Myalina* sp., *Natica* sp., *Bellerophon*, *Cucullæa* sp., *Sanguinolaria?* sp., *Euomphalus*, *Macrocheilus*, *Pleurotomaria*.
LOWER DEVONIAN.	WOODSBAY BEDS.	Impure slates, resembling the Lynton beds, here and there red gritty beds.	*Favosites cervicornis*, *Fenestella antiqua*, *Orthis arcuata*, *O. granulosa*, *Pterinea spinosa*, *Bellerophon striatus*, *Pleurotomaria aspera*, *Chonetes Hardrensis*, *Tentaculites scalaris*.
	LEE BEDS.	... ...	*Megalodon cucullatum?*, *Tentaculites* sp.
	VALLEY OF ROCKS.	Dark-grey slates and numerous fossils, in casts, weathering rusty.	*Favosites cervicornis*, *Petraia* sp., *Fenestella antiqua*, *Chonetes sordida*, *Orthis arcuata*, *Spirifera canalifera*, *S. hysterica*, *S. lævicosta*, *Streptorhynchus umbraculum*.
	LYNTON BEDS.	Grey sandy slates and fine grits, cleaved, passing into calcareous banded slates and earthy fossiliferous limestones, with Brachiopoda, Polyzoa, Crinoidea.	*Alveolites suborbicularis*, *Favosites cervicornis*, *Actinocrinus tenuistriatus*, *Fenestella antiqua*, *Chonetes Hardrensis* (*sordida*), *Orthis arcuata*, *O. granulosa*, *Spirifera canalifera*, *S. hysterica*, *S. lævicosta*, *Ctenodonta krachtæ*. Fish-remains.
	FORELAND BEDS.	Massive, coarse, and fine-grained grey, purple, and green grits; base nowhere visible.	No fossils; plant-like remains occur, but are doubtfully organic.

Youngest Devonian in North Devon.—In ascending order, above the Pickwell Down Old Red Sandstone or the purple and Red Sandstones of Morte Bay, we have—

1. A band of pale, nearly white, slates (Vention beds).
2. A thick series of greenish-grey grits with bands of *Cucullæa* and *Avicula damnoniensis* and olive-coloured shales, with numerous *Lingula mola*.
3. Alternating beds of calcareous sandstone, pale shales, and thin nodular bands of limestone and cleaved slate, rich in fossils, succeed (*Croyde beds*), nearly 500 feet in thickness. The abundant fossils are *Avicula damnoniensis* and *Rhynchonella laticosta*—many Pelecypoda in the lower part. The characteristic Brachiopoda are *Strophalosia caperata* and *Spirifera disjuncta*, which range through the whole series of beds. This last series comprises the Pilton group of Phillips; and its aspect in the wild and grand coast section of Baggy Point and Croyde Bay, where they "reef" the foreshore in fine succession, can only be paralleled by the Carboniferous slates of Pembrokeshire as they lie upon the unfossiliferous beds of the Upper Old Red Sandstone; but the Pilton and Baggy groups represent a series unknown in Pembrokeshire, or only represented by a few feet of strata at the base of the Carboniferous slate. The pale slates (with *Adiantites hibernicus*) which underlie the Marwood beds from Baggy Point determine the base of the fossiliferous series.

The quarries of Sloly, Marwood, Braunton, and Baggy contain the following fauna; it will be seen how few species pass upwards into the Carboniferous series. (See also the complete stratigraphical succession of the Devonian series and their fossil contents, pp. 170–173.)

Fauna of the Marwood Series—

The calcareous sandstones or brown limestones contain *Cucullæa trapezium*, *C. Hardingii*, *Nucula antiqua*, *Avicula Damnoniensis*, *Nucula*, *Schizodus*, *Modiola*, *Edmondia* sp., *Orthonota* sp., *Spirifera disjuncta*, and *S. laminosa*, *Rhynchonella pleurodon*, species of *Platyschisma*, *Macrocheilus*, *Pleurotomaria*, *Orthoceras*, and *Bellerophon*, probably *B. bisulcatus*.

In the olive-green shales the following plant-remains occur: *Bornia* (*Calamites*) *transitionis* (Göppert), *Lepidodendron*, (*Knorria*) *dichotomum* (Haught.), with *Lingula mola*. Annelide burrows are exceedingly abundant.

Pilton Beds Fauna—

The Pilton group succeeds these olive shales; they are calcareous and argillaceous, composed chiefly of grey slate and finely laminated calcareous sandstone; near the base both Brachiopoda and Lamellibranchiata abound. The characteristic forms are *Avicula Damnoniensis*, *Strophalosia* (*Leptæna*) *caperata*, *Spirifera disjuncta*, *Productus prælongus*, *Orthis interlineata*, and *Phacops latifrons*, *Curtonotus*, *Nucula*, *Modiola*, *Chonetes* (small sp.), *Bellerophon* and *Aviculopecton* (three species). The Crinoidea are represented by *Actinocrinus*, *Poteriocrinus*, and *Rhodocrinus*. The whole must have been accumulated in a shallow sea.

Carboniferous Slate—

Undulating beds of slate and bands of sandstone commence the Carboniferous beds. It is, however, difficult to precisely fix the line where the Pilton group ends and the Carboniferous commences. *Spirifera laminosa*, *S. ovalis*, *S. bisulcatus*, *S. cuspidatus*, *Streptorhynchus crenistria*, *Chonetes Hardrensis*, *Athyris Roysii*, *Bellerophon decussatus*, *Productus costatus*, *P. martini*, *Orthis Michelini*, and *Phillipsia seminifera* are the chief species in these slates, and determine them.

This slate lies troughed in and among the contorted beds of the Pilton group, but immediately south of Barnstaple the true Carboni-

ferous limestone sets in, although impure in character. The quarries of Venn and Swinbridge, &c., contain the highly typical *Posidonomya Becheri* and *Goniatites*. This North Devon type of the Carboniferous series differs entirely from that of any other British locality, both as regards the underlying limestones and the succeeding beds of the lower coal measures, in which there are no workable coals above the impure and thin culm seam at Bideford. These barren shales, grits, and sandstones extend southwards for thirty miles, as far as Boscastle; again resting upon the Upper Devonian beds of Bossiney and Grawer, with interbedded greenstones, but without a vestige of carbonaceous matter, or any organic remains whatever. The Carboniferous rocks of the *southern border of this culm trough* are unconformable upon the Upper Devonian, whether by "faulting" or overlap is doubtful; at Boscastle and Grawer the unconformity is due to an extensive east-and-west fault with much disturbance. To the eastward, on the same strike, at Petherwin and Launceston it is clearly seen. That the Petherwin group of North Cornwall is below the North Devon Barnstaple beds, admits of no doubt; they are the equivalents of the slates below the Baggy beds at Morte Bay (Vention beds), and rise at Petherwin from beneath the overlying grits and shales of the culm measures. Between 60 and 70 species of mollusca have been obtained at Petherwin and Landlake, which, with the exception or addition of Goniatites (3 species) and Clymenia (7), agree in all particulars with the fauna of the Marwood beds in the Northern area.

Petherwin Fauna—

The Petherwin fauna was deposited under deeper water conditions than that of Marwood and Pilton. The Actinozoa of Petherwin through *Petraia celtica*, *Amplexus tortuosus*, and *Cyathophyllum cæspitosum*, the Cephalopoda through *Goniatites insignis*, *G. bisulcatus*, and *G. biferus*, Clymenia with its seven species, *C. lævigata*, *C. striata*, *C. linearis*, *C. fasciata*, *C. sagittalis*, *C. pleurisepta*, and *C. valida*, clearly tend to ally these North Cornwall beds with the Clymenia kalk of the Rhenish area, and, in the absence of the above ten species, with the beds below the Baggy series in North Devon. Numerically the Petherwin fauna is as follows:—*Actinozoa* 3 species; *Polyzoa* 2; *Lamellibranchiata* 12; *Brachiopoda* 20; *Gasteropoda* 8; *Heteropoda* 1; *Cephalopoda* 17; (*Orthoceras* 5; *Cyrtoceras* 1; *Nautilus* 1; *Goniatites* 3; *Clymenia* 7). These 17 species alone through the Cephalopoda exhibit a facies essentially and entirely differing from the Carboniferous, and with other physical evidence tend to show that the fauna of the Upper Devonian on the south side of the great arenaceous culm basin was deposited in a different and subsiding area.

The slates of Tintagel, Grawer, and De la Bole, south of Petherwin, differ entirely from those of the northern area. The pale grey and drab shales, slates, and limestones of Petherwin greatly resemble those of Ilfracombe, and, in the absence of sandstones, &c., bear evidence of deeper sea accumulation.

Contemporaneous Igneous Rocks.—The Upper Devonian slates and lowest part of the culm measures in the *southern area* are greatly interstratified with contemporaneous or interbedded volcanic rocks. These occur immediately at the junction of the culm measures and

Upper Devonian slates (near Boscastle and Grawer); but are generally more or less associated with the latter. None are known in the northern area, but one or two thin greenstone dykes traverse the upper part of the Ilfracombe series at Lee and Morte.

Lundy Island.—The southern end of Lundy Island (thirteen miles from the North Devon coast) is composed of Middle Devonian slates of the "Morte Hoe" type, and is intersected in every direction with vertical or highly inclined greenstone dykes and white quartz veins; the granite being completely separated from the slates by a dyke many feet wide. No less than sixty of these dykes occur on the eastern side of the island, in most instances traceable through or across from east to west; many also traverse the granite from north to south, forming a complete network. These dykes vary from 2 feet to 50 feet in width; they are trachytic, amygdaloidal, augitic, hornblendic, and doleritic, many weathering into bomb-like spherical masses. Those traversing the slates at the south end of the island stand up like isolated walls of masonry, passing out to sea in many directions. The part severance of the slates from the granite is due to the density of a large diorite dyke, which has produced the altered or metamorphosed condition of the slates against the walls of the dyke, rendering them easily decomposed. Probably no island or coast section in Britain exhibits in the space of $2\frac{1}{2}$ miles such an assemblage of dykes through true granite.[1] It is probable that the age of these dykes is post-Carboniferous, but their isolation from the associated Upper Devonian rocks of North Cornwall, in which dykes of the same age seldom occur, renders correlation difficult as to age.

In the midst of the undulating culm measures at Yealm Bridge and north of Petherwin, a faulted anticlinal exhibits the Barnstaple series, the only trace of this series south of Barnstaple, the dip being north and the *culm* beds unconformable. These higher beds in this small "inlier" afford conclusive proof that the Pilton group overlies the Petherwin beds.

Representative Beds of South Wales and the Welsh Borders.—There is perfect conformity and actual passage in the Ludlow area and Welsh border from the uppermost Silurian into the lowermost beds of the Old Red Sandstone[2] (or the "Cornstone group"). This is the direction in which lie the tracts of the south of Ireland on the one hand, and Devonshire on the other, and probably, owing to the overlap of the Old Red Sandstone near Caermarthen over the lower Silurian rocks, the passage beds are hidden. We may assume that the Pickwell-Down Sandstone of North Devon and the Old Red Conglomerate of the south of Ireland are represented by the "White Sandstone and Conglomerate" that underlie the "Limestone shale," which represents in a greatly reduced condition a form of the *carboniferous slate* of the south of Ireland, and the Barnstaple,

[1] A MS. map has been prepared, showing every dyke, its inclination, thickness, character, and bearing, both for the slates and granite, on the east and west sides of the island.

[2] "Siluria," 4th edition, p. 246.

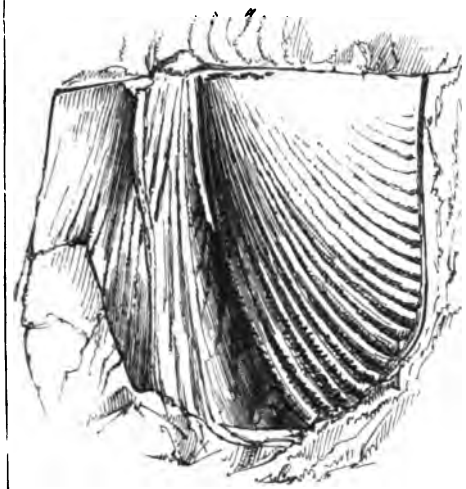
PLATE VIII.

DEVONIAN FOSSILS.

1. *Spirifera disjuncta* (Sow.) Middle and Upper Devonian. British and Foreign.
2. *Stringocephalus Burtini* (Def.) Middle Devonian.
3. *Cucullæa trapezium* (Sow.) Middle and Upper Devonian.
4. *Calceola sandalina* (Lim.) Middle Devonian.
5. *Cyrtoceras tridecimale* (Phill.) Middle Devonian.
6. *Murchisonia spinosa* (Phill.) Middle Devonian.
7. *Section of Clymenia levigata*, showing position of siphuncle at base of chamber.
8. *Cucullæa Hardingii* (Sow.) Middle and Upper Devonian.
9. *Strophalosia productoides* (Murch.) Middle and Upper Devonian.
10. *Head of Phacops granulatus* (Münst.) Upper Devonian.
11. *Cystiphyllum vesiculosum* (Goldf.) Coral, and characteristic of the Middle Devonian.

PLATE VIII.

DEVONIAN FOSSILS.



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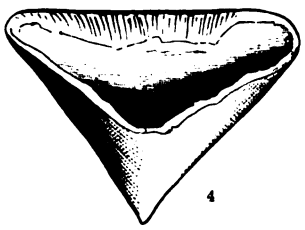

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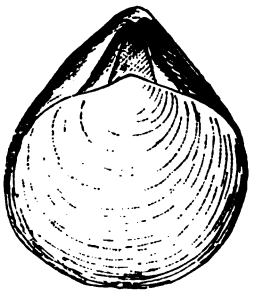

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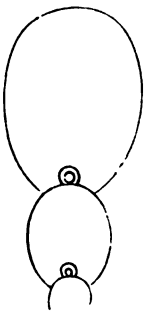

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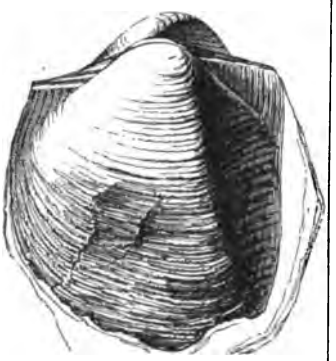

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Pilton, and Marwood beds, of North Devon. This is confirmed on fossil evidence, for in the same shales in Pembrokeshire have been collected numerous species characteristic of the Pilton and Marwood beds, viz.:—*Avicula Damnoniensis* (special type), *Cucullæa trapezium*, *Rhynchonella laticasta*, *Bellerophon bisulcatus*, and species of *Pleurotomaria*, *Nucula*, *Sanguinolites*, *Modiola*, *Axinus*, and *Discina*.[1]

"Between these two horizons lie the Red, Grey, and Greenish Sandstones and marls of the 'Cornstone group,' which must, therefore, represent the Middle and Lower Devonian beds deposited under conditions differing from those under which the Devonshire strata were formed." Some physicists are of opinion that these beds are *lacustrine*.[2] Professor Hull suggests with much reason, as more probable, that they "were of *estuarine origin*, and connected with the open sea which spread over the Devonian region to the south." Hence, while the *Devonian estuary* over the area lying to the north of the Severn was unfitted for *Molluscan*, *Cœlenterate*, and *Crinoidal* life, these organisms flourished abundantly in the more open and purer waters of the sea which ranged over Devonshire, the south of England, and eastwards towards the Rhine. The suggestion, therefore, by Professor Hull, that these Cornstone beds be termed "*Lacustrine Devonian beds*," rather than "Old Red Sandstone," a name to which they have no title, deserves every consideration.[3]

The Lower Devonian or Lynton Group has yielded 34 genera and 47 species; the Middle Devonian, 101 genera and 262 species; the Upper Devonian, 71 genera and 167 species. This excludes the fishes of the Old Red Sandstones, which, as before stated, number 50 genera and 120 species.

Constant research has failed to detect any organic remains in the red sandstones between Porlock and Lynton or the Foreland, and the lowest members of these Lower Red Sandstones are nowhere exposed in this area. Immediately east of the river Lynn commence the slates of the lower group, containing *Spirifera lævicosta*, *Orthis arenata*, and *Steganodictyum* (fish-remains). These lower slates are about 1500 feet thick, and at Lee and Woodabay they are conformably overlain by the Hangman grits. *Fenestella antiqua*, *Orthis arenata*, *O. granulosa*, *Spirifera lævicosta*, *Pterina spinosa*, *Pleurotomaria aspera*, *Bellerophon globatus*, *B. striatus*, *Orthoceratites*, *Tentaculites*, &c., characterise these lower slates at Lee and the Valley of Rocks, &c. No one can fail to distinguish this division of the Devonian series, and the entire succession is to be seen in the cliffs west of Lynmouth.

[1] Salter, Quart. Jour. Geol. Soc., vol. xix. p. 478.

[2] Professor Ramsay and Mr. Godwin Austen.

[3] The thickness of the "Cornstones" is probably not so great as is generally believed; sections given by the Geological Survey (on sheets 3 and 5) show the rocks to be from 2500 to 600 feet.

Conclusions Relative to the Lower Devonian Series in North Devon:—

1. The great series of the Foreland red sandstones and grits is nowhere seen in its entire thickness, neither the base nor upper portions being clearly visible.
2. The great series of red and grey sandstones constituting the base of all the North Devon and West Somerset deposits, is the oldest of the Palæozoic series exposed in that area.
3. The dip on the northern side of the anticlinal is much greater than on the southern [a mean of fourteen observations along the strike for thirteen miles determined it to be 34°]. No organic remains occur in these Lower Red Sandstones.
4. South of the anticlinal of the valley of the East Lynn, and reposing upon the sandstones, there occur fossiliferous grey and purple slates and grits with subcrystalline beds of limestone about 1200 feet thick. These are the Lower Devonian slates or the Lynton group.
5. The fauna of this lower group is purely marine, entirely differing from that of the Silurian epoch, and numbering 34 genera and 47 species.
6. Succeeding these lower slates and conformable to them, there occurs a second great series of red gritty sandstones nearly devoid of fossils. These are the Hangman, Oare Hill, and Exmoor grits, which constitute the base of the succeeding Middle Devonian or Ilfracombe slates and limestones, but which physically connect the two groups above and below.
7. A marked and important difference occurs in the structure of the slate masses as well as the fossil grouping in these two areas, a change by which both may be correlated and co-ordinated with those of South Devon on the one hand, and the Rhenish, Belgian, and French deposits on the other.

Lower Devonian Fossils of North Devon and West Somerset:—

ACTINOZOA.—*Alveolites suborbicularis, Favosites cervicornis, Petraia pleuriradialis.*
CRINOIDEA.—*Actinocrinus tenuistriatus.*
POLYZOA.—*Fenestella antiqua.*
BRACHIOPODA.—*Chonetes sordida* or *C. Hardrensis, Orthis arenata, O. granulosa, Spirifera canalifera, S. hysterica, S. lævicasta, Streptorhynchus crenistra.*
PELECYPODA.—*Pterinea spinosa, Ctenodonta krachiæ.*
GASTEROPODA.—*Pleurotomaria aspera, Bellerophon striatus.*

Palæontology of the Lower Devonian Fauna of North Devon and West Somerset.

Eighteen species occur in North Devon, and seven are common to that area and to one or other of the three European areas, the Rhine, Belgium, and France. These seven are important forms; few, perhaps, compared with the richer European fauna, but closer research would probably give us better evidence for correlation. The rare occurrence also of beds of limestone in the Lower Devonian series is one and another reason why a richer fauna does not occur. The seven species that connect the British with the Continental Lower Devonians are *Alveolites suborbicularis, Favosites cervicornis, Fenestella antiqua, Chonetes sordida, C. Hardrensis, Spirifera canalifera, S. hysterica,* and *S. lævicosta.* Comparison with the Lower Devonian rocks of South Devon shows that only one species (*Leptæna laticosta*) is com-

mon to both areas. The above analysis is amongst the Lower North Devon species only, but of the eighteen named, no less than thirteen also occur in the Middle Devonian of either North or South Devon. Regarding the distribution of life over this area, it is not a little singular that only one species of Gasteropoda, *Pleurotomaria aspera*, is *known in* the Lower Devonian rocks, only four species of Pelecypoda, viz., *Pterinæa spinosa*, *P. anisota*, *Ctenodenta krachtæ*, and *Aviculopecten*, and one Cephalopod, *Orthoceras gracile*, with *Bellerophon bisulcatus*, and *B. striatus*. These are from the Lower Devonian series of Cornwall; with the exception of the ubiquitous *Atrypa reticularis*, which is certainly common both to the Silurian and Devonian rocks, we have no reliable species connecting these two great life periods.

The British *Lower Devonian* rocks have as yet only yielded a single Gasteropod and Cephalopod, and only 12 genera and 31 species of Brachiopoda. What became of the Upper Silurian fauna, either of the Cornish area, or across what is now the Bristol Channel (both of which, with the exception of the Llandovery and Wenlock series at Tortworth north of Bristol, are the nearest known Silurian areas), we cannot conjecture. Whether they became extinct or not, we know of no reappearance in any area, or any recurrent fauna.

Middle Devonian.—Many localities in North Devon testify to the value of the middle division of the Devonian rocks. Typical sections are to be seen at Heddon's Mouth, the Little and Great Hangman, West Challacombe, Combe Martin, Ilfracombe, and Watermouth. The history of the middle series or "Ilfracombe group" is written in the coast sections from Combe Martin Bay to Ilfracombe, particularly so in the fine sections of slates and shaly limestones and grits of Hagginton Beach and the Hill quarries.

Fauna.—These slates have yielded the following species, which fully establish the middle position of the rocks. The Brachiopoda abound, and are special witnesses to the value of the division, and they are also nearly all European or Continental species (Rhenish, Belgian, and French).

BRACHIOPODA.—*Spirifera disjuncta*, *S. glabra*, *S. curvata*, *S. nuda*, *S. speciosa*, *Merista plebeia*, *Atrypa reticularis*, *A. desquamata*, *A. aspera*, *Athyris concentrica*, *Cyrtina heteroclyta*, *Orthis interlineata*, *O. striatula*, *Rhynchonella pleurodon*.

GASTEROPODA, &c.—*Acroculia vestuta*, *Euomphalus serpens*, *E. radiatus*, *Natica* sp., *Tentaculites*, *Conularia*, *Fenestella*, and *Favosites cervicornis* also occur.[1]

Faunal Distribution.—In the slates and limestones at the above places and others, the entire assemblage of the Middle Devonian fauna occurs. Seventy-three species have been determined from the argillaceous and calcareous rocks of the group, and 35 of these occur in one or other of the three European areas selected for comparison. Thus 46 per cent. are common to the Middle Devonian strata of Britain and Western Europe. It is due to the excess of limestone at

[1] See tabular distribution of the North Devon Devonian fauna, p. 170 173.

Torquay, Newton, and Plymouth in South Devon, over that of the north, that we owe the *Cœlenterate fauna* of South Devon. Lonsdale long ago referred them to an extensive formation existing between the Silurian and Carboniferous systems, or occupying the stratigraphical place of the Old Red Sandstone, whatever may be the exact relation of this marine Devonian group to that great and almost unfossiliferous formation.

It will, therefore, be seen from the Table, p. 205, that the fauna of the Middle Devonian consists of 109 genera and 279 species. The Protozoa number 7 species; the well-known Stromatopora 5, *S. concentrica* and *S. placenta* being most characteristic. The Cœlenterate or coral fauna is large, comprising no less than 25 genera and 53 species. Our knowledge of Cœlenterate life would lead us to believe that it only requires research, probably in or through certain zones (yet to be ascertained), to greatly add to the species of these genera, their rarity entirely depending upon oceanic bathymetrical range or depth.

Brachiopoda.—The Brachiopoda of the Middle Devonian greatly predominate over every class, their number being specifically double that of any other in the Devonian rocks; the two genera *Rhynchonella* and *Spirifera* are largely represented; the former by 20 species, and the latter by 14, *Athyris* 5, *Atrypa* 6, and *Cyrtina* 4. The 24 genera in the *Middle Devonian* are illustrated by 83 species, out of 115 known in all three divisions; 8 genera stand out conspicuously with one representative species only. They are—

Camaraphoria rhomboidea, Davidsonia Verneuilii, Merista plebeia, Productus subaculeatus, Retzia ferrita, Stringocephalus Burtini, Strophalosia fragaria, and *Uncites gryphus.*

These, then, are the essentially characteristic forms of the Brachiopoda that occur in and determine the Middle division of the Devonian rocks.

Pelecypoda.—Only 16 genera and 26 species are known in the Middle division, 11 genera being represented by only one species in each. They are—

Clidophorus, Corbula, Ctenodonta, Leptodomus, Modiola, Myalina, Mytilus, Orthonota, Pullastra, Sanguinolaria, and *Schizodus.*

Three of the 26 species pass to the Carboniferous rocks and connect the two formations.

Gasteropoda.—Twelve genera and 37 species illustrate the Middle Devonian Odontophora. They are—

Acroculia 3 species; *Euomphalus* 5; *Loxonema* 5; *Macrocheilus* 6; *Murchisonia* 4; *Nerita, Natica, Scoliostoma,* and *Trochus,* 1 species each; *Pleurotomaria* 6; *Turbo* and *Vermetus,* 2 each.

Only 2 of the 37 species are North Devon forms, but 15 are European, and 4 pass to or survived into the Carboniferous period.

Nucleobranchiata or Heteropoda.—*Bellerophon striatus* and *Porcellia Woodwardii* are the only two genera known in the middle division of South Devon.

Cephalopoda.—The species in this class seem to have been distributed or localised in groups and colonies, the two genera *Clymenia* and *Cyrtoceras* especially so. The former, *Clymenia*, both in Europe and Britain, is mainly confined to the Upper Devonian, notably so at Petherwin and Land Lake in North Cornwall; 11 species occur in the Upper Devonian below the Marwood beds, and south of the great culm trough the species of Cyrtoceras seem to have been equally locally distributed, 12 species being confined to the Middle Devonian of Newton Bushel in South Devon. The analysis of the 237 Middle Devonian species of South Devon shows, as we have seen, close affinity to the fauna of Rhenish Prussia, Eifel, Belgium, and France, as a large percentage of the species common to each can be adjusted to and collated with our Devonian types. Five genera, *Clymenia* (2 species), *Cyrtoceras*, *Goniatites*, *Nautilus*, and *Orthoceras*, out of the 12 known species of Cyrtoceras, *C. nodosum*, *C. ornatum*, and *C. tridecimale*, are Eifelian.

Comparison between the Faunas of North and South Devon.—This extensive Southern Middle Devonian group, numbering 237 species, is connected in the Northern Devonian area by only 50 species,—*i.e.*, 50 of the 237 southern forms occur in North Devon; yet we are enabled to correlate the species occurring in *South Devon* with those of the Rhenish area through 86 species; but only 31 North Devon forms are at present known to be common to the Rhenish, Belgian, or French areas. As regards original distribution, this is an important correlation, and looking at the great development of limestone in the Southern Devonian area, and the rich Brachiopod and Cælenterate or Coral life occurring in them as compared with the North Devon, we are led to believe either that the southern area was accumulated in much deeper and purer water, or in a different or slightly connected area. Taking these two groups or classes (the *Brachiopoda* and *Actinozoa*) as types of development in the Devonian seas, we find that in the southern region or South Devon, 24 genera and 67 species of Brachiopoda are known; but in the northern or North Devon area, only 15 genera and 21 species. Through the Corals the same relationship exists in both areas, 25 genera and 52 species occur in the southern limestones, and only 13 genera and 18 species in the less developed and impure beds in the northern. The same hypothesis applies to the Echinodermata, the 4 genera and 9 species in the South Devon rocks having hitherto no representative in North Devon. It is, however, through the *Gasteropoda* and *Cephalopoda* that the relationship or correlation is so incomplete. The South Devon series contains 12 genera and 32 species of Gasteropoda, but only 6 species occur in the North Devon beds. It is more marked still with the Pelagic Cephalopoda and Nucleobranchiata; the former through *Cly-*

menia 2, *Cyrtoceras* 12, *Goniatites* 4, *Nautilus* 1, and *Orthoceras* 8, in all 27 species, have only five representatives in the extended area occupied by these rocks in North Devon. These all being pelagic, oceanic, or free swimming forms, we should expect to find them fairly represented in both regions. The identity of species between the two areas is rendered difficult from the difference in the petrological aspect and structure of the strata; hence, their community may be questioned. It will be readily seen that in South Devon the position of the middle group can only be clearly determined through Palæontological research; the stratigraphical or successional sequence in the southern area being obscured through igneous and other physical disturbances; whereas in North Devon the physical sequence is clear and unmistakable, and although a smaller fauna, the zoological contents of the rocks are reliable. Knowing that 237 species occur in South Devon, we must collate them or adopt them as our standard for comparison with the northern species in the middle zone. Fifty of the known 237 species are common to the two areas, which are further related through a marked facies, one distinctly characteristic of, and identical with, the Middle or Eifelian and Stringocephalon-kalk of the Rhenish provinces. This occurs both through the Brachiopoda and the Cælenterata (*Actinozoa*). Twenty-one species of Brachiopoda in North Devon, out of 67 South Devon forms, are common to the middle zone of both areas, and 17 of the 21 occur in the European Middle Devonian. Comparison among the Corals (*Actinozoa*) differs only so far as regards numbers. Of the 50 species known in South Devon, 18 are also common to it and the North; *no species out of the* 50 lived on to the Carboniferous period. As before stated, the great development of limestone in South Devon fully accounts for the larger number of known species of corals over that of the northern area.

CHAPTER XIX.

CORRELATION OF THE DEVONIAN ROCKS.

Few researches into the history of the British rocks have led to more important results than the investigations into the history of the succession and place of the Devonian rocks of North and South Devon. Comparison has been made into rocks believed to be of the same—or equivalent—age in Ireland, and areas north of the Severn; and has also been carefully instituted between the Devonian and Carboniferous

series, as they occur in Belgium, Scotland, and Ireland, so as to establish on a still firmer basis the value of the Devonian system.[1]

The Scotch and Irish beds of this age differ from all others, the Irish Coomhola beds, with *Anodonta* and *Palæopteris* or *Adiantites*, being undoubtedly of Upper Devonian or Upper Old Red Sandstone age. Mr. Kinahan would class the Old Red Sandstone of the Dingle and Cork area as Lower Carboniferous, and corresponding in the Limerick area to the same series of sandstones and shales. He also states that in no place in Ireland has the Old Red Sandstone a defined upper boundary, one group graduating into the other. Furthermore, only in Munster and in the hills between Lough Erne and Pomeroy, in the counties of Fermanagh and Tyrone, is the Old Red Sandstone at the absolute base of the Carboniferous formation; as in all other places the rocks so called and described are on different geological horizons, ranging up to the base of the coal-measures.[2]

Professor Hull has shown that *between the* "Glengariff beds" of the South of Ireland, and the succeeding formations, either of Old Red Sandstone or Carboniferous age, there is a wide hiatus of unrepresented time, so that over a given and limited area certain rocks were not continuously or synchronously deposited, and cannot be compared with those of an assumed or acknowledged type. This missing portion or "hiatus" is filled up in the south and south-west of England, and in Belgium, by the great series known as the "Middle" and "Lower" Devonian beds in North Devon, lying between "the Foreland grits" on the one hand, and the "Pickwell Down Sandstone" on the other. It may be assumed "*that while a moderately deep sea*, in which were deposited the Middle and Lower Devonian beds, overspread the south of England and adjoining continental areas, *land* conditions prevailed in the south of Ireland during the same period." Points of analogy and contrast have been instituted between the Old Red Sandstone of the South of Ireland and its representatives in North Devon, Belgium, and Scotland.

Carboniferous and Old Red Sandstone Series.—The descending series of beds below the Carboniferous Limestone in North Devon and the south of Ireland are well known, but it is essential to compare them together in order to obtain a clear idea of the succession in the two areas.

Comparison with the South of Ireland.—The yellow sandstone of the South of Ireland cannot be separated from the Old Red Sandstone, but the yellow sandstone of the North of Ireland is the base of the Carboniferous limestone, containing carboniferous fossils only. The Carboniferous slate which overlies the yellow sandstone thins away in Kilkenny, Waterford, and Wexford, becomes thicker from Cork to Bantry, and is interstratified at its base with grits. Near Glengariff the *Coomhola* grits measure 3000 feet thick.

[1] Quart. Jour. Geol. Soc., vol. xxxvi., "On the Geological Relation of the Rocks of the South of Ireland to those of North Devon," &c. Professor E. Hull, M.A.

[2] "Geology of Ireland," pp. 50–94.

These analyses with other evidence show :—

1. That in the South of Ireland the yellow sandstone is the upper part of the Old Red Sandstone.
2. That the Carboniferous slate, whether thickly or thinly developed, contains, especially in the upper part, the ordinary Carboniferous types.
3. That a local but considerable group intervenes, physically more connected with the Carboniferous, but distinct as to fossils. The same plants occur as in the Upper Old Red Sandstone (Upper Devonian), also some few and peculiar shells of the Carboniferous limestone. This group is in part the equivalent of the Marwood sandstones and the Pilton series.

Descending Series in the South of Ireland :—

1. *Carboniferous Limestone.*—Coralline, crinoidal, and shelly limestone, sometimes cleaved (thinning towards the south-west).
2. *Carboniferous Slate* (*top beds*).—Black slate with calcareous bands full of fossils—black and grey slate with few fossils.
3. *Coomhola Grit.*—Grey and olive-green slates and tilestones with fine-grained, hard grey grits, with marine shells and some plants, the whole having a maximum thickness of (in Co. Cork) 5000 feet.
4. *Old Red Sandstone.*—"Kiltorcan beds :" fine-grained, yellowish, greenish, and reddish sandstones, and shales with fish. (*Asterolepis, Bothriolepis, Glyptolepis, Coccosteus*, and *Pterichthys*). Also the bivalve shell, *Anodonta Jukesii*, the only pelecypod mollusc known in the Old Red Sandstone, with plants (*Adiantites.*) These pass down into massive, reddish-brown, and purple, soft sandstone having a *conglomerate base*—the whole about 3000 feet thick.

"The basal conglomerate of the Old Red Sandstone is everywhere unconformable to the rocks on which it rests over the south of Ireland; this condition is equally conspicuous, whether it refers to the contact of the conglomerate with the uppermost Silurian beds in the Dingle Promontory, or to the Lower Silurian beds of the Comerah or Galtee Mountains; on the other hand, all the beds from this conglomerate *upward*, into the Carboniferous Limestone, are in perfect conformity with each other, notwithstanding the change from the apparently fresh-water '*Kiltorcan beds*' into the marine '*Coomhola-Grit* series' which succeeds them."

It is clear that lacustrine conditions prevailed over the area of the South of Ireland during the deposition of the Kiltorcan series, and thus by their fossil and physical relations they correspond with the deposits of those ancient great inland lakes which modern geologists regard as the basins of deposit for the Old Red Sandstone.

The line of division between the Old Red Sandstone and the Carboniferous series in Ireland, is traceable at the base of the Coomhola-Grit series, or at the top of the Kiltorcan beds, which contain *Anodonta* and *Palæopteris.*

The accompanying section shows the structure of the North Devon Carboniferous and Upper Devonian rocks, ending with the Upper Old Red Sandstone of Pickwell-Down, to or above the Morte-Hoe and Ilfracombe Middle Devonian slates.

DESCENDING SERIES, NORTH DEVON AND WEST SOMERSET.

(Carboniferous and Upper Devonian.)

Carboniferous Limestone (Venn Quarry). Dark earthy carbonaceous limestone in regular beds (*Posidonomya Becheri*).

Carboniferous-Slate Series (Barnstaple beds). Top beds, dark schists (contorted) resting on light-grey slates, with calcareous nodules. *Cyathocrinus distans*, &c., seen at Barnstaple station.

"*Pilton beds*" (Phillips). Slates of a purplish or greyish tint, Brachiopods, crinoidal stems, and a Trilobite (*Phacops latifrons*); thin intermittent bands of limestone are common, and are highly fossiliferous.

"*Cucullæa*-zone" (Hall), also called "Marwood beds" by Jukes and Salter. Light-grey and olive-green slates with bands of hard grit, and calcareo-ferruginous beds with three species of *Cucullæa*. These beds are shown in the railway cutting north of Braunton Church.

Below the above are found (east of the village of Upcot) yellowish and greenish flags and shales, passing downwards into purple sandy shales and grits, sometimes of a pale-green colour, similar in appearance to the "Kiltorcan beds."

"*Pickwell-Down Sandstone.*" Purple and red sandstones with thin shaly bands in the upper part; greyish grits, sometimes massive, with thin shaly bands, in the lower; no fossils; the bands of shale, though requiring to be mentioned, are quite unimportant.—(*Hull.*)

That the "Pilton" and "Cucullæa" or Marwood beds are the equivalents of the "Coomhola" grits and slates of the south of Ireland, and therefore of Lower Carboniferous age, is evidenced by the community of species to a large extent.

The following species are common to the Pilton and Marwood beds of North Devon, and to the Coomhola beds of the south of Ireland, as determined by Mr. W. H. Baily of the Irish Survey:—

BRACHIOPODA.—*Chonetes hardrensis*, *Rhynchonella pleurodon*, *Streptorhynchus crenistria*, *Strophomena rhomboidalis* (var. *analoga*), *Productus scabriculus*, *Spirifera Urii*, and *Lingula squamiformis*.

PELECYPODA.—*Cucullæa Hardingii*, *C. trapezium*, *C. amygdalina*, and *Avicula damnoniensis*.

The accompanying table shows the general agreement between the Lower Carboniferous and Upper Devonian, or Old Red Sandstone, in each district.

REPRESENTATIVE BEDS.

	SOUTH OF IRELAND.	NORTH DEVON.
Lower Carboniferous beds	Carboniferous Limestone.	Carboniferous Limestone.
	Carboniferous slate.	Barnstaple beds.
	Coomhola grit and slate (Passage beds).	Pilton beds.
		Baggy and Marwood beds (*Cucullæa*-zone).
Old Red Sandstone, or Upper Devonian	Kiltorcan beds.	Upcot beds.
	Old Red Sandstone and conglomerate.	Pickwell-Down Sandstone.—(*Hull.*)

Middle and Lower Devonian Beds.—The great series of marine fossiliferous strata which underlie the Pickwell-Down Sandstone in

North Devon (all except the barren Morte-Hoe Slates immediately under them), constituting the Middle and Lower Devonian series, are not represented in the south of Ireland, but the accompanying is a concise description of them and their succession in North Devon:—

DEVONIAN

MIDDLE.

1. *Morte-Hoe Slates.* Glossy micaceous slates, uniform in texture, and such as might have originated from the waste of gneiss or mica-schist: unfossiliferous.
2. *Ilfracombe Beds.* A variable series of grey slates and thin grits, containing numerous bands of blue earthy limestone ("*Stringocephalus*-limestone"), chiefly in the lower part. These beds are highly fossiliferous, containing *polyzoa*, *corals*, and *mollusca* in abundance.
3. *Hangman Grits* (Martinhoe beds of T. M. Hall). Hard, fine-grained, red, purple, and grey grits, with bands of slate rising from below the Ilfracombe slates at Combe-Martin Bay. These beds, like those of the Pickwell-Down Sandstones, form high tablelands or downs, traversed by deep dells.

LOWER

4. *Lynton Slates.* Greyish sandy slates and fine grits, cleaved, passing down into calcareous banded slates and earthy limestones, in places highly fossiliferous. These beds break off into scarped cliffs, ridges, and tors along well-developed planes of jointage. *Corals*, *po'yzoa*, *crinoids*, *brachiopoda*, &c., are abundant.
5. *Foreland Grits.* Massive coarse and fine-grained grey, purple, and green grits, with bands of schist. Pebbles of quartz, quartzite, and slate sometimes occur. The beds are contorted, and their base is nowhere visible. Fucoid and linear plant-remains occur, resembling those from the Glengariff beds of Ireland.—(*Hull.*)

The Middle Devonian Fauna (or those fossils occurring in the Ilfracombe beds) amounts to 73 known species, of which about 20 come from the Lower Devonian or Lynton beds, and 28 from the Middle Devonian series pass up to the Carboniferous. Not a single form out of either the lower or middle divisions has occurred in the Glengariff grits or slates of Ireland. The most careful estimate of the thickness of the Devonian beds of North Devon has been attempted by Dr. Haughton, who estimates that—

(*a.*) "From the lowest beds at Lynmouth, occupying the summit of the great Anticlinal Arch, up to the Ilfracombe Marine Limestone" = 4400 feet.

(*b.*) "From the Ilfracombe Limestone to the *Cucullæa* and plant beds of Baggy Point and Marwood = 5200 feet, or, the whole of the Devonian beds proper = 9620 feet."

(*c.*) "From the *Cucullæa* and plant beds to the flinty calcareous shales or slates of Barnstable = 2200 feet, or 11,820 in all."

Absence of the Middle and Lower Devonian Series in Ireland.—According to the views of Professor Hull,[1] these two divisions are not represented in Ireland, the Old Red Conglomerate of the South of Ireland having no immediate predecessor in the formations of that area. The "hiatus" and unconformity between the Glengariff beds, on the one hand, and the Old Red or Lower Carboniferous beds on the other, shows that certain strata are absent over this area. If this correlation is rightly indicated between the two groups—the Devonshire and Irish sections—it thence follows that the Middle and Lower Devonian beds exactly occupy the place of the missing strata in the South of Ireland, where there must have been interruption in the stratigraphical succession after the formation of the Glengariff or Dingle beds.

No one who has ever examined the area south of the Pickwell-Down Sandstone can doubt that the Baggy, Marwood, Croyde, Barnstaple, and Pilton beds are upon the same general horizon as the Carboniferous slate and Coomhola grits of Ireland, and that the Pickwell Down Sandstones represent the Upper Old Red Sandstone of the south of Ireland. Both on physical and palæontological grounds these two groups seem to agree. Although the freshwater bivalve shell *Anodonta Jukesii* has not occurred in the Baggy or Pilton series in North Devon, its plant associate, *Adiantites* (*Palæopteris*) *hibernicus*, has been found in the Baggy beds, or immediately above the Pickwell-Down Sandstone (Upper Old Red). We may well believe therefore that the "lacustrine" conditions of the South of Ireland gave place to marine conditions over the Devonian area during the same time.

The Glengariff series may measure about 10,000 feet in thickness. There is a total absence of the Old Red Sandstone at the base of the Carboniferous. Contortions in the Glengariff beds are of earlier data than the deposition of the Old Red Sandstone or Carboniferous beds; this, therefore, implies that, as stated, between the Glengariff beds and the Old Red Sandstone there is a vast amount of wanting strata, indicative also of unrepresented time—in other words, a wide gap and prolonged interval of time actually separates the two formations. The representation (or filling up) of this gap Mr. Hull endeavours to show through the uninterrupted sequence in the Middle and Lower Devonian beds of North Devon, or through the whole series from the lowest Devonian up to the base of the Carboniferous formation in that area. In no other district do we find evidence to account for such loss, or beds that can be correlated with those of the South of Ireland. The accompanying table shows the succession of the Carboniferous and Devonian rocks of North Devon and the South of Ireland, and is intended to exhibit their relation and probable contemporaneity:—

[1] "On the Geological Age of the Rocks forming the Southern Highlands of Ireland," Quart. Journ. Geol. Soc., vol. xxxv. p. 699 *et seq.* (1879).

	North Devon.	South of Ireland.
Lower Carboniferous series.	Earthy limestones, with *Posidonomya* (Venn Quarry).	Carboniferous limestone.
	Barnstaple slates.	Lower Carboniferous slate.
	Pilton beds.	Coomhola grits and slates (with *Cucullæa* &c.)
	Marwood beds (*Cucullæa*-zone).	
Upper Devonian.	Upcot flagstones.	Kiltorcan beds (with *Anodonta Jukesii*).
	Pickwell-Down sandstones.	Old Red Sandstone and conglomerate.
Middle Devonian.	Morte-Hoe slates.	Strata absent over the area in the south of Ireland.
	Ilfracombe limestone group.	
	Hangman grits (Martinhoe beds).	
Lower Devonian and Upper Silurian.	Lynton shales and limestones.	Glengariff beds, passing down into the Upper Silurian beds.
	Foreland grits (base invisible).	

The above is probably the true reading of the areas under notice.

Scotland.—The latest researches by Professor A. Geikie[1] into the history of the Old Red Sandstone of Scotland show (as we have just seen) that there are but *two divisions*,—a "*Lower*" passing down conformably into the Upper Silurian Shales, and an "*Upper*" graduating upwards into the Lower Carboniferous or Calciferous Sandstones, with a discordance between the two series. These relations correspond exactly to those of the Glengariff beds of the south of Ireland on the one hand, and of the Old Red Sandstone on the other.

The "Lower Old Red Sandstone" of Scotland consists of sandstones, shales, and conglomerates, containing a rich assemblage of fishes, no less than 36 genera and 85 species occurring therein, associated with a large number of *Eurypteridian crustacea*.

The "Upper Old Red Sandstone" consists of red and yellow sandstones with a *base of conglomerate*. Physically, the resemblance between the Irish and Scotch groups is complete. The Vertebrate fauna of this Upper division is smaller than that of the Lower, comprising only 15 genera and 25 species. The great hiatus which exists in Ireland (between the Old Red Sandstone Conglomerate and the Glengariff beds) occurs also in Scotland between the Upper and the Lower Old Red Sandstone. Mr. Geikie has shown that the Lower Old Red Sandstone of the north of Scotland (Lake Orcadie) was completely isolated from that of the borders of Wales (*the Welsh lake*), which may have been an estuary opening into the sea in the direction of the Bristol Channel, Devonshire, and the south-west of England. This alone would account for the complete dissimilarity in the Ichthyic fauna of the two regions.

Deductions from Representative Formations.—Prof. Hull, from his researches, believes that there is really in the British Isles, as elsewhere, *only one formation* of "Old Red Sandstone" properly so

[1] Quar. Jour. Geol. Soc., vol. xvi. p. 312, and Trans. Roy. Soc. Edinb., xxviii. p. 347.

called—namely, the *upper member* of that name in Scotland; the *Yellow Sandstone* and conglomerate *below* the Carboniferous limestone of South Wales and Hereford; the *Pickwell-Down Sandstone of North Devon*, and the *Old Red Sandstone and conglomerate of the south of Ireland*.

The accompanying table (xx., p. 190) of Representative Formations will assist in showing the correlations of the four divisions through the five areas of Ireland, North Devon, South Wales, Scotland, and Belgium.

If the above views are correct, it follows—

1. "That there is *only one formation which can be properly called the Old Red Sandstone*. This is represented in North Devon by the *Upper Devonian Sandstone of Pickwell Down;* by the Old Red Sandstone and conglomerate (including the Kiltorcan beds) of the south of Ireland; the Upper Old Red of Scotland, and the *Psammite du condroz* of France and Belgium.
2. "That the Lower Old Red Sandstone of Scotland is the Lacustrine representative of the uppermost Silurian beds of the English and Welsh borders, and of the Glengariff beds of the South of Ireland, and forms the connecting link between the Silurian and Devonian formations.
3. "That the hiatus between the Upper and Lower Old Red Sandstone of Scotland, and between the Old Red Sandstone and Glengariff beds in Ireland, is filled up in Devonshire by the Middle and Lower Devonian formations.
4. "Assuming that the Foreland grits are on the one hand (in part) the equivalents of the Upper Ludlow rocks, and of the Glengariff beds on the other, it would appear that all over the British Islands (except the South of England and the Welsh borders), land conditions prevailed from the close of the Upper Silurian stage throughout the Lower and Middle Devonian stages. At the close of the latter, we have evidence that there was a general re-submergncee, with the formation of lakes and estuaries during the Upper Devonian or Old Red Sandstone period." [1]

These researches serve to show or suggest, with every probability, that at the close of the Upper Silurian Period—represented in Ireland by the Glengariff beds, in Wales by the Upper Ludlow and Passage beds, and in Scotland by the Lower Old Red Sandstone—there was a general elevation of all the northern and western portions of the British Isles, followed by denudation. It was otherwise in the south-west of England and adjoining continental districts. *Continuous depression* must have gone on here, the sea overspreading the extensive area in which were deposited the Lower and Middle Devonian rocks. "With the deposition of the *Upper Devonian stage*, or *Old Red Sandstone proper*, the submersion of the western and northern portions of the British Isles began; Lacustrine or Estuarine conditions were established over the South of Ireland, portions of Scotland, and the North of Ireland. In the waters of these lakes the Old Red Conglomerates and succeeding beds with *Anodonta* were laid down."

[1] See Professor Hull, Q. Jour. Geol. Soc., vol. xxxvi. pp. 255–274 (*loc. cit.*)

TABLE XX.—*Representative Formations: Devonian and Old Red Sandstone.*

Formations.	Ireland.	North Devon.	South Wales, &c.	Scotland.	Belgium.
Lower Carboniferous Series.	Carboniferous Limestone. Carboniferous Slate. Coomhola Grits.	Carboniferous Limestone. Barnstaple Slate. Pilton and Marwood beds.	Carboniferous Limestone. Limestone Shale.	Carboniferous Limestone. Calciferous Sandstone Series.	Carboniferous Limestone. Shales.
Upper Devonian, or Old Red Sandstone.	Kiltorcan beds. Old Red Sandstone and Conglomerate.	Upcot Flags. Pickwell-down Sandstone.	Red and yellow Sandstone and Conglomerate.	Red Sandstone and Conglomerate.	Psammite du Condroz.
Middle Devonian. Lower Devonian.	Absent. (Great hiatus.)	Mortehoe Slates. Ilfracombe Series. Hangman Grits. Lynton beds.	Cornstone Group.	Absent. (Great hiatus.)	Schistes de Famenne, Calcaire de Frasne. (Spirifera disjuncta.) Red Sandstone and Marls. Calcaire de Givet. (Stringocephalus Burtini.)
Passage- and Upper Silurian beds.	Glengariff Grits and Slates. Ludlow, Wenlock, and Llandovery beds.	Foreland beds. (Base not seen.)	Passage- and Upper Ludlow beds.	"Lower Old Red Sandstone."	Poudingue de Burnot. (Hiatus.)

Foreign Equivalents of Devonian Rocks.

The uppermost beds of the Silurian, or base of the Lower Old Red, are the so-called *Tilestones or Passage-beds* of Murchison. Salter proposed for them the better term "Ledbury shales."

1. Lower Devonian "*Coblentz Sandstone*," Lower or Cornstone group of Old Red Caithness flags of Scotland .	Characterised by *Cephalaspis*, *Pteraspis*, and *Pterygotus*.
2. Middle Devonian, *Eifel*, and Plymouth limestone, Ilfracombe, and Coombe Martin, or North Devon slates, &c.	*Stringocephalus*, *Calceola*, and the great mass of the Actinozoa, *Rensselæria*, *Uncites*, &c.
3. Upper Devonian, yellow and red sandstones, *Cypridina schist*, *Flintz*, and *Kramenzel stein*; Petherwin group, Pilton group, Marwood group, Dura Den beds, Scotland	*Holoptychius*, *Glyptopomus*, *Phaneropleuron*, *Cucullæa trapezium*, *Avicula Damnoniensis*, *Spirifera disjuncta*, *Athyris concentrica*, *Strophalosia subaculeata*, *Phacops granulatus*.

Comparison with the Devonian series of the Rhenish provinces enables us to correlate our three divisions with the work of Von Decken and the officers of the German Geological Survey.

1. Ardennes-Schiefer, Coblentz-Schichten (or Spirifera Sandstone), Wissenbach-Schiefer.	Truly represented by our Lynton and Fowey groups in North Devon and Cornwall.
2. Lenne-Schiefer, Eifel-Kalk . .	Plymouth, Torquay, and Newton limestone, and the Ilfracombe and Combe-Martin limestones in North Devon.
3. Cypridinen-Schiefer, including the Goniatite Shales, Flinz, and Kramenzel-Stein with Clymenia .	Petherwin and Landlake group in North Devon, and probably the Vention beds in Morte Bay, North Devon.
4. Verneuilii-Schiefer, Argillaceous Sandstone	Marwood and Pilton group, with the same fossils.

At Aix-la-Chapelle these Verneuilii beds rest upon Eifel-kalk, or the Middle Devonian series, without the intervention of the Cypridina schist, and are themselves immediately covered by the Kohlen-kalk or mountain limestone. This fact has much value with relation also to our North Devon section, for we have as yet failed to detect in North Devon any unconformity between the Marwood series and the other members of the Devonian formation. Unconformity, however, between the Upper and Lower Old Red of Ireland and Scotland has long been known through the researches of Sir R. Griffith, Murchison, Jukes, the Survey of Ireland, and Professor Geikie in Scotland.

The rocks of the Boulonnais were long ago described by M. Rozet in his Memoir on that district,[1] and ably discussed by Mr. Godwin Austen and others. The yellow sandstone group, "*Grès à unio*" of Rozet, is the *Marwood sandstone of Austen*. There can be no doubt as to the age of this sandstone, the occurrence of *Cucullæa trapezium*, *C. Hardingii*, defining that unequivocally. Below these Marwood sandstones succeed the *Château de Fiennes shales and clays*, again followed by the "*Ferques limestone*," containing abundance of *Spirifera*

[1] Bulletin de la Soc. Géol. de France, 1840, vol. x. p. 404.

disjuncta. This Ferques limestone is doubtless the equivalent of our *Pilton group*, the fossils, species for species, being the same.

Rhenish Prussia.—In Rhenish Prussia, in the Eifel district, the Devonian strata represent the following horizons and successions:—[1]

The *Goniatite* schists.....	Marly Limestone, Upper Devonian.
Cuboides (*Rhynchonella*) limestone.....	
Stringocephalus-schist.....	Marl, Middle Devonian.
Calceola-schist.....	
Cultrijugatus-Stufe (*Spirifer*).....	
Vichter schist.....	Sandy schists, Lower Devonian.
Ahrian schist (Dumont).....	
Coblentzian.....	

German Devonian.—F. A. Römer, of Clausthal, has correlated the parallel horizons or deposits of the Harz and the Eifel. In the Eifel he gives 7 divisions, in the Harz 8; they are compared with Aix-la-Chapelle and Couvin.

In the "Palæontographica" (for 1854), Römer divides the Devonian rocks of the Harz into 9 portions:—

1. Amay schists (jüngere Grauwacke).
2. *Cypridina*-schist.
3. *Goniatite*-schist.
4. Iberg limestone.
5. *Receptaculites*-schist.
6. *Stringocephalus*-limestone.
7. *Orthoceratite* or Wissenbach schist.
8. *Calceola*-schist.
9. *Spirifera*-sandstone (ältere or Rhenish Grauwacke).

Characteristic fossils are given with each, and the chief localities where the beds are exposed.

The Fichtelgebirge, through the researches of Prof. C. W. Gümbel,[2] exhibit 4 divisions or groupings:—

1. *Cypridina*-schist.....	Upper Devonian (in 3 stages).
2. *Calamopora*-schist.....	Middle Devonian.
3. *Tentaulite*-schist.....	
4. *Nereite*-schist.....	Lower Devonian.

Belgian Beds.—The splendid sections from the Carboniferous Limestone, down to or near the base of the Devonian, exhibited in the valleys of the Meuse and Ourthe in Belgium, must convince every student of the great importance of the two formations amongst the deposits of Northern Europe, fully justifying the position assigned to them amongst the Continental groups. That the Devonian beds of Belgium palæontologically represent those of the North Devon is clear. Physically, the limestones predominate in Belgium, and the sedimentary beds in Devonshire, especially in North Devon; it may be difficult to determine the representative beds in Belgium and Devonshire, but it is possible that the "*Psammite du condroz*" may repre-

[1] Zeitschrift d. deutschen geol. Gesell. Jahrg. 1871, p. 375.

[2] "Palæontographica," Dunker and Meyer, xi. p. 109, "Ueber Clymenien in den Uebergangsbilden des Fichtelgebirges."

sent, or be the equivalent, of the Pickwell Down sandstones, near Ilfracombe; although the Belgium *psammite* is a marine deposit containing *Spiriferæ*, &c., and is overlain by fossiliferous shales representing the "lower limestone shale" of England, a division of the Carboniferous Limestone of much importance in the West of England, and the South Wales coalfield. The *calcaire de Frasne*, with the well-known Upper Devonian *Spirifera disjuncta*, underlies the *Psammite du condroz*, and is recognised in the Upper Devonian states of Tintagel in West Cornwall. The "*calcaire de Givet*," with its important limestones, represents the Ilfracombe and Plymouth beds on the one hand, and the Eifel limestone on the other.

Franco-Belgian Area.—The Devonian of the Franco-Belgian region are divided by M. Gosselet into Upper, Middle, and Lower, but with differences which have palæontological value.[1]

His Upper Devonian contains the Psammites du Condroz in 2 divisions; the Schistes de Famenne in 4 divisions.

The Middle Devonian one large group (calcaire de Givet) divided into 9 beds or bands.

In the Lower Devonian, Gosselet places (1) the schistes à Calcéoles (in 3 divisions), (2) Poudingue de Burnot, (3) the Grauwacke à *Leptæna Murchisoni* (in 2 divisions), (4) the Couches de Gedinne and conglomerates and schists (in 3 divisions).

The Boulonnais.—The Palæozoic series of the Boulonnais consists entirely of the Carboniferous, Upper Devonian, and Middle Devonian series, the Lower being, so far as we know, absent.

The annexed table shows the representative beds in North Devon and their French synonymes or equivalents.

TABLE XXI.—*Section of the Palæozoic Series of the Boulonnais, with their Synonymes and Equivalents.*

	Coal-measures of Locquinghen.	
	Hardinghen Sandstone (Millstone Grit).	
Carboniferous Limestone.	Limestone with *Productus giganteus*.	
	Napoleon marble, *P. undatus*.	
	Haut-banc Limestone, *P. cora*.	
	Dolomite, with Crinoids.	
Upper Devonian.	Fiennes Sandstone, with *Cucullæa Hardingii*.	Upper part: Marwood beds, or Coombola Grits.
	Red Clays and Shales.	Lower: Pickwell-down Sandstone.
	Ferques Limestone, *Spirifer Verneuilii*.	Calcaire de Frasne.
	Shales of Beaulieu and Dolomite of Nores.	
Middle Devonian.	Blacourt Limestone, *Orthis striatula*	Calc. de Givet, or Ilfracombe beds.
	Conglomerates, red Shales and green Sandstones of Blacourt. Ferns and Calamites.	Hangman Grits, &c.

Lower Devonian absent. The Lower Silurian beds underlie the Middle Devonians.—(*Hull.*)

[1] Annales des Mines, 6e sér. tom. xii. p. 595.

The following are some of the more abundant forms:—*Atrypa concentrica*, *Rhynchonella pleurodon*, *Spirifera bouchardi*, *S. disjuncta*, *Strophalosia caperata*, and *Phacops latifrons* (*P. latreillii*).

M. Gosselet enumerates the chief divisions as follows:—

			English Equivalents.
Carboniferous.	1. Coal grits and shales. 2. Upper Carboniferous limestone (Visé). 3. Lower Carboniferous limestone (Tournay).		Carboniferous.
Upper Devonian.	4. Psammites de Condroz.	=	Marwood beds with *Phacops latifrons*, *Athyris concentrica*, *Spirifera Verneuilii*, and *Strophalosia scabriculus*.
	5. Slates of Famenne.	=	Petherwin beds and Upper Newton Bushel limestone, containing *Rhynchonella cuboides*, *Spirifera Verneuilii*, *Cardium palmatum*, &c.
Middle Devonian.	6. Givet limestone.	=	Plymouth, Torquay, and Ilfracombe limestones.
	7. Calceola slate.	=	Shales and limestones (Chircombe, &c.)

Regarding the Upper Devonian series of Saxony, Nassau, the Hartz, and Westphalia, it is doubtful if the Pilton and Marwood beds are represented or present in these districts, as the Carboniferous limestone rests at once upon the *Clymenia limestone*, our Petherwin group. In the Rhenish provinces, in Belgium, and in the north-west of France, the Marwood group, however, is present. This distribution lends additional strength to the inference that the Marwood group may be unconformable to the Middle and Lower Devonian series.

We have thus referred to some of the chief European localities and systems to show the importance and development of the continental Devonian rocks with their enormous fauna, as compared with the clearly determined but comparatively poor British series, our whole fauna numbering only 577 species at most. Unless some reference had been made to the continental European Devonians, no force could have been given to the system; and its geographically disjointed state tends to detract from the original unity of the whole, but at the same time to show that it was, and has been, one of the most extensive systems on the Continent. Even in the British Islands its importance would be seen, could we but uncover the extensive area between Belgium, the Boulonnais, and Devon and Cornwall, now deeply buried under the Secondary and Tertiary systems.

American Devonian Rocks.—We cannot pass over the Devonian formation of North America and the Canadas, either physically or palæontologically, for we know, through the labours and researches of Hall, Bigsby, Newberry, Meek, Shumard, Winchell, Dawson, and others, how great and widely extended is the Devonian system in North America, and how persistent are its conditions and successions.

The state of New York and the Canadas, with the Gaspé region in the east, have as yet exhibited the Devonian rocks in fullest development, all the three great horizons being present. The Hamilton and Upper Helderberg groups, with the Catskill, Chemung, and Portage groups above, occur in the States of Pennsylvania, Ohio, Illinois, Missouri, and Michigan in full development. In Iowa and Tennessee the Upper Devonian only is present. In New York State the eleven recognised divisions make up a mass of limestones, sandstones, shales, flagstones, and conglomerates upwards of 8000 feet in thickness. In Pennsylvania the Devonian rocks are 12,000 feet thick. The great Middle or Hamilton group is developed in six of the eight States, the Lower or Helderberg in four. Principal Dawson, in his "Acadia," has shown that the Devonians of the St. John's area, New Brunswick, exhibit peculiar features differing from those of the Western States before mentioned, but nevertheless divisible into three stages or horizons.[1]

The above generalisations relative to the development and distribution of the American Devonians tend, like that of the European area generally, to show their great value and extent as compared with the comparatively poor fauna of the British Islands. That the whole formation or system once extended universally over the area thus roughly traced, there cannot be any doubt. Probably during one general age some one or other of its three divisions may have occurred homotaxially. As a whole, the Devonian period occupied all that time or epoch extending from the close of the Upper Ludlow to the base of the Carboniferous. In North Devon its upper member passes insensibly and conformably into the Carboniferous, which is itself abnormal in condition.

[1] Acadia, 2d ed., pp. 503-505.

TABLE XXII.—*Showing European and American Equivalents of the Three Divisions or Stages of the British Devonian Rocks.*

Britain.	France and Belgium.	Germany.	Russia.	America.	
Upper Devonian, or Upper Old Red Sandstone (*Famennien*).	Schistes de Famennes. Calcaire de Frasne et Couche à Rhynchonella cuboides.	Clymenien-Kalk et Cypridinen-Schiefer de Nassau Prusse. Rhénane et de Saalfeld (Thuringa) avec plantes terrestres.	Dévonien Supérieur de Russie.	Catsgill group. Chemung group. Portage group. Genessee group.	Erie Division.
Middle Devonian, or Middle Old Red (*Eifelien*).	Calcaire de Givet Belgique. Schistes à Calceola Sandalina.	Eifel-Kalk ou Stringocephalen-Kalk. Calceola Schiefer de la Prusse Rhénane.	Calcaire Dévonien Moyen de Russie.	Tully limestone. Hamilton group. Marcellus slate.	
Lower Devonian, or Lower Old Red (*Coblencien*).	Poudingue de Burnot. Grauwacke à Leptæna Murchisoni.	Orthoceras-Schiefer. Spiriferen-sandstein ou Rhénische Grauwacke de Coblenz Nassau, &c.	Dévonien Inférieur de Russie. Avec Poissons du Vieux Grés rouge.	Carboniferous limestone. Onondaga limestone. Schoharie grit. Caudagalli grit. Oriskani sandstone.	Upper Helderberg.

TABLE XXIII.—*Correlation of the Devonian and Old Red Sandstone Groups for Devonshire, Cornwall, South Wales, Scotland, Ireland and Belgium.*

Horizons or Stages.	North Devon.	South Devon.	Cornwall.	South Wales.	Scotland.	South of Ireland.	Belgium.
Lower Carboniferous series.	Barnstable beds (part).	Carboniferous beds.	Carboniferous series. Boscastle, &c.	Carboniferous, Tenby, &c.		1. Carboniferous limestone. 2. Lower Carboniferous slate. 3. Coomhola grit series (passage bed).	Carboniferous limestone, grey and reddish shales and grits.
Upper Devonian or Upper Old Red Sandstone.	Pilton, Braunton, Croyde, Marwood, Sloly, Baggy, and Upcot beds, with the Pickwall-Down sandstones at the base (Morte Bay series).	No representative except probably near Newton Bushel.	Petherwin limestone and slates, Tintagel and De la Bole slates.	Pembroke section (in part), yellow sandstones, serpula beds, & Upper Old Red Sandstone.	Yellow and Red Sandstones, Dura-Den beds *Holoptychius, Pterichthys*, the Lammermuir Hills, Fifeshire sandstones.	1. Kiltorcan beds with anodonta. 2. Old Red Sandstone and conglomerate at base.	Psammite du Condroz.
Middle Devonian or Middle Old Red Sandstone?	Mortehoe, Wooldcombe, Rockham, and Lee slates, Ilfracombe and Combe-Martin slates, grits, sandstones, limestones, the Hangman grits at the base.	Dartmouth slates, Dartington, Ogwell, Torquay, Newton and Plymouth limestones, Lummaton, Ramsleigh, &c.	Padstow, Looe grits (=Hangman beds), Polperro.		No known Middle Old Red Sandstone in Scotland.	Hiatus. No representative.	Schistes de Famenne, Calcaire de Frasne (Spirifera disjuncta), Calcaire de Givet (Stringocephalus Burtoni), Schistes à Calceola Sandalina.
Lower Devonian or Lower Old Red Sandstone.	Heddon's Mouth, Woodabay, Lee, Valley of Rocks, Watersmut, Lynton, and Lynmouth slates, &c. The red grits and sandstones of the Foreland, Countessbury, Glenthorn, &c. &c., at the base.	Meadsfoot slates, with *Phyllolepis concentricus*, Yealmpton-Creek & Black-Hill shales, Looe Island.	St. Veep, Pobman, Polperro, and Fowey grits and slates.	Lower part of cornstones, &c., Old Red Sandstone.	Forfarshire and Caithness flagstones, &c., Ross and N.-E. Highlands, *Cephalaspis, Pteraspis, Dipterus, Coccosteus, Pterygotus*, &c.	No representative.	Sandstones, schistes, and conglomerates (Poudingue de Burnot).

CHAPTER XX.

THE DEVONIAN FAUNA.

THE fauna of the Devonian rocks is indisputably marine; 211 genera and 577 species are known in Britain, among which the *Hydrozoa* is the only class unrepresented.

The *Actinozoa* (corals) abounded, and the species are all peculiar. No single form passed to the Carboniferous, and none passed or came from the Silurian sea into the Devonian deposits; and throughout European or American areas this is the same. Nearly every British species occurs in Rhenish Prussia, France, and Belgium. The *Rugosa* are illustrated by 18 genera, and the *Tabulata* by 7. The species number 55. *Cyathophyllum*, *Acervularia*, *Hallia*, *Smithia*, *Endophyllum*, and *Petraia* are the chief of the rugose corals; and *Favosites*, *Pachypora*, and *Alveolites*, or the *Favositidæ*, are the only perforate *Madreporaria*, and with *Heliolites* and *Tetradium*, amongst the *Alcyonaria*, individually abound. The MIDDLE DEVONIAN group contains all the 25 genera, and 53 of the 55 species. The LOWER DEVONIAN has hitherto only yielded 5 genera and 8 species, and the UPPER DEVONIAN beds 5 genera and 7 species. These Upper Devonian are important forms, closely approaching Carboniferous types. They are *Amplexus tortuosus*, *Cyathophyllum cæspitosum*, *C. ceratites*, *Fistulipora cribrosa*, *Michelinia antiqua*, *Petraia celtica*, and *P. pleuriradialis*.

Contrasted with the Crustacean Fauna of the Upper Silurian, especially through the Trilobita, the change and diminution of species in the Devonian are marked features. In the Wenlock rocks, no less than 27 genera and 78 species are known; in the Caradoc, 37 genera and 146 species, mostly Trilobita. The Devonians yield 36 species. Only 7 Trilobita occur in Britain, viz., *Bronteus*, *Calymene*, *Cheirurus*, *Harpes*, *Homalonotus*, *Phacops*, and *Phillipsia*. The whole known Devonian Crustacean fauna for Europe and America consists of 45 genera and 290 species; 200 of these are Trilobita, the remaining belong to the *Merostomata*, *Phyllopoda*, and *Ostracoda*.

The Devonian Molluscan fauna in Britain is rich only when the Brachiopoda are included. They number 114 species out of the known 289 of all classes, the Pelecypoda 63, and the Gasteropoda 45, the Heteropoda 8, the Pteropoda 1, and the Cephalopoda 60. The Brachiopoda nearly reached their maximum of development in Britain during the Devonian period. *Generically* they exceeded the Carboniferous in the ratio of 26 to 20; but the *species* in the Carboniferous series number more than in the Devonian. 64 genera and 1200 species of this one class have been described as ranging through the Devonian system of Britain, Europe, America, and Australia. The genus Pro-

ductus, which plays so important a part in the fauna of the Carboniferous Period, was represented in the Upper Devonian sea by 5 species, and through *Productus horridus* lived on into the Permian.

The Middle Devonian genera *Stringocephalus* and *Uncites* are probably the most characteristic of the Brachiopoda, and determine in the most marked manner the position of the Middle Devonian series throughout Europe. The Pelecypoda of the British Devonian rocks are few compared with those of Rhenish Prussia and America, for out of the 90 genera and 900 species known, we possess only 23 genera and 63 species, 26 of which occur in the Middle, and 48 in the Upper Devonian. On the Continent and America, as with us, those genera richest in species are *Pterinæa*, *Aviculopecten*, *Grammysia*, *Cucullæa*, and *Curtonotus*, &c. The Univalves or Gasteropoda are fewer or poorer in genera, but richer in species as compared with the Pelecypoda, in the ratio of 13 to 23 in the genera, and 45 to 63 in the species. The most careful research has been made relative to the history and distribution of the Devonian fauna of Britain, owing to the anomalous position which the Devonian rocks hold stratigraphically, in relation to the succeeding Silurian and Old Red Sandstone and Carboniferous beds. The fauna we have no doubt about; its stratigraphical base and summit, however, are yet unsatisfactory in the British Islands. The great group of the Tetrabranchiate Cephalopoda are largely represented in our Devonian rocks, 6 genera and 60 species occurring. The representative genus *Clymenia* yield 11 species in the Upper Devonian, *Goniatites*, 12, and *Cyrtoceras* 12 species from the Middle division; *Orthoceras* through 15 species represents all three divisions of the Devonian rocks.[1]

The Ammonites of the secondary rocks (Trias to close of Chalk) have their first representatives in the genus Goniatites from the Upper Devonian of North Cornwall, the Petherwin beds yielding 5 species, and the Middle series of Torquay 12; the European Devonian rocks have yielded 170 species of this genus, and the Carboniferous series of Britain 53.

As regards the Vertebrata of the Devonian proper, we have little evidence save through a few fish, the great fish fauna of the rocks of this age being confined to the true Old Red Sandstone, and chiefly to Scotland. *Coccosteus*, *Pterichthys*, and *Ctenacanthus* are said to occur in the Harz, Eifel, and Thuringia,[2] *Palædaphus devoniensis*, and *Byssacanthus Gosseleti* (two remarkable sharks) have been found in the North of France and Belgium area. One other link between the Devonian and Old Red Sandstone Proper, has occurred in the sandy portion of the Upper Devonian (or the *Psammite de condroz* of Belgium) through the detection of *Holoptychius nobilissimus*. These help to connect the two types of rocks together; but the great mass of fishes (some 60 species) occur in the Lower and Upper division of the true Old Red Sandstone in Scotland, to be hereafter noticed.

[1] These groups will be discussed under the head of the Palæontology, or Life and Distribution, when treating of them stratigraphically.

[2] Zeitsch. Deutsch. Geol. Gesellschaft, xxix. p. 423.

PLATE IX.

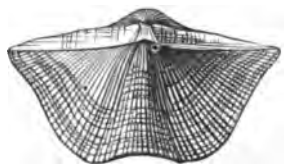
DEVONIAN FOSSILS.

1. *Stromatopora polymorpha* (Goldf.) Middle Devonian. South Devon.
2. *Hexacrinus interscapularis* (Phill.) Middle Devonian. South Devon (basal plates).
3. Apex of *Hex. interscapularis.*
4. *Heliolites porosus* (Goldf.) Middle Devonian. South Devon.
5. *Spirifera disjuncta* (Sow.) Upper Devonian. North and South Devon (*passim*).
6. *Strophalosia productoides* (Murch.) Middle and Upper Devonian.
7. *Stringocephalus Burtini* (Defr.) Middle Devonian. North and South Devon.
8. *Atrypa desquamata* (Sow.) Lower and Middle Devonian. North and South Devon.
9. *Megalodon cucullatum* (Sow.) Middle Devonian. South Devon.
10. *Clymenia linearis* or *undulata* (Münst.) Middle Devonian. South Devon.
11. *Murchisonia bigranulosa* (D'Arch.) Middle Devonian. South Devon.

PLATE IX.

DEVONIAN FOSSILS.

10



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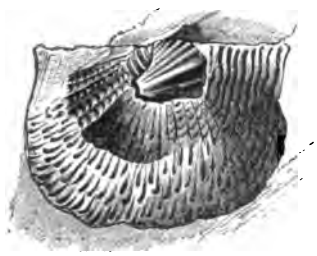

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Alveolites 4, *Cyathophyllum* 11, *Favosites* 5, *Smithia* 3, *Endophyllum* 2, and *Petraia* 4. The remaining genera are only represented by 1 species in each; 21 species are common to the rocks of North and South Devon, and 25 occur on the Continent (Rhenish Prussia, Belgium, and France); none pass to the Carboniferous rocks in any region. The Middle Devonian Cœlenterata contain all the 25 genera and 53 of the 55 species. The Lower has hitherto only yielded *Alveolites suborbicularis, Cyathophyllum helianthoides, Favosites cervicornis, Petraia celtica, P. gigas, P. pleuriradialis, P. bina?* and *Pleurodictyum problematicum;* the Upper Devonian *Amplexus tortuosus, Cyathophyllum cæspitosum, C. ceratites, Fistulipora cribrosa, Michelinia antiqua, Petraia celtica,* and *P. pleuriradialis.*

The Upper and Lower Devonian rocks of North Devon are chiefly composed of slates, with here and there bands of impure limestones. They therefore possess but a small coral fauna; whereas the highly developed masses of Middle Devonian limestone around Torquay, Newton Abbot, and Plymouth, are simply coral reefs or masses of great magnitude. In North Devon, between Ilfracombe and Linton, the limestones are lenticular, thin, and impure; yet more than one-half of the entire known Devonian Actinozoa occur in them, and we have evidence of beds below low-water level near Ilfracombe yielding even finer specimens than at Torquay.

Echinodermata.—Nine genera of Crinoidea, 3 Asteroidea, 1 Cystoid, and 1 Blastoid are all that are known of this class in the British Devonian rocks. Eighty genera have been described from the Devonian series of Europe and America.

The Asteroidea are mostly from the Upper Devonian of North Devon. The chief genera are—*Protaster, Palæaster, Helianthaster, Pentremites, Adelocrinus, Actinocrinus, Cyathocrinus,* and *Taxocrinus.* Of the whole fauna (28 species) only *Actinocrinus triacontadactylus, Cyathocrinus ellipticus, C. geometricus, C. pinnatus, C. variabilis,* and *Pentremites ovalis* pass to the Carboniferous rocks.

Annelida.—*Serpula advena* occurs in the Upper Old Red Sandstone of Caldy Island, and *Tentaculites annulatus?* in the Middle Devonian limestones near Ilfracombe.

Crustacea.—All the 5 orders, illustrated by 17 genera and 36 species, are represented in the British Devonians. Only 7 genera of Trilobita are known, viz., *Bronteus* (*flabellifer*), *Cheirurus* (*articulatus*), *Harpes* (*macrocephalus*), *Homalonotus* (*elongatus*), *Phacops* (5 species including the subgenera *Trimerocephalus* and *Cryphæus,* and *Phillipsia* (*Brongniarti*). The Merostomata are *Eurypterus,* 6 species, *Stylonurus* 6, and *Pterygotus* 6, and are, with one or two exceptions, Lower Old Red Sandstone types. None of these are known to occur in the typical Devonian area, being either in the Scotch or Silurian regions. The singular genus *Prœarcturus* (*P. gigas*) of the family Idoteidæ is from the Old Red of Herefordshire; this and *Proricaris M'Henrici* of Baily are the only 2 new British genera known in the Devonian fauna.

Polyzoa.—The Tubuliporidæ through *Ceriopora,* the Reteporidæ

through *Fenestella*, *Hemitrypa*, *Polypora*, *Ptylopora*, and *Retepora*, and the Escharidæ through *Glauconome*, are represented in the Devonian rocks by the above 7 genera with 11 species; all the genera are also Carboniferous, 4 species only being common to both formations —*Ceriopora similis*, *Fenestella plebeia*, *Glauconome bipinnata*, and *Polypora laxa*. The Lower Devonian yields only 2 species, viz., *Fenestella antiqua*, occurring in the Middle and Upper, and *Retepora repisteria*, which is also Middle. The European, American, and British Polyzoa consist of 26 genera and 115 species; and, as before stated, of these we possess only 7 genera and 11 species.

Brachiopoda.—With the exception of the fishes of the Old Red Sandstone (120 species), this is the largest group in the British Devonian rocks. We should expect this when we know that no less than 61 genera and over 1100 foreign described species have passed through the hands of European, American, and British palæontologists. Of these 1100 species only 114 are British. *Davidsonia*, *Cyrtina*, *Rensseleria*, *Camarophoria*, *Stringocephalus*, and *Uncites* are the genera which first made their appearance in our area during the Middle Devonian period, the most marked and prolific of the three horizons.

The Lower Devonian yields 12 genera and 31 species—*Athyris*, *Atrypa*, *Chonetes*, *Leptæna*, *Orthis*, *Rhynchonella*, *Spirifera*, *Spiriferina*, and *Streptorhynchus*. The Middle division contains 24 genera out of the 26, and 83 of the 114 species. The Upper contains 15 genera and 36 species; of these 10 genera and 16 species pass to the Carboniferous. It is essential to the history of the Devonian fauna that we name the genera—*Athyris*, *Chonetes*, *Discina*, *Lingula*, *Productus*, *Rhynchonella*, *Spirifera*, *Streptorhynchus*, *Strophomena*, and *Terebratula*. The chief genera are *Rhynchonella*, containing 22 species, *Spirifera* 19, *Streptorhynchus* 6, *Orthis* 7, *Cyrtina* 4, *Productus* 5, and *Terebratula* 4. Regarding the great discrepancy or smallness of this peculiar fauna as compared with that of the Continent and America, we must have regard to the smallness of the area *now exposed* in England as *compared with the original area occupied* by the Devonian sea, the accumulations of which are now covered by the Secondary and Tertiary rocks of the west and east of England, the Devonian floor or old sea-bed being now hidden east of the Quantocks, North Devon, and Torquay, but *known to occur* and range east of the meridian of London, doubtless joining the Belgian and Rhenish rocks of the same age under the German Ocean.

Pelecypoda (Lamellibranchiata).—The mass of the species in this class occurring in the Upper Devonian, and specially abundant, are Asiphonida, through *Aviculopecten*, *Pterinæa*, and the Mytilidæ. Twenty-three genera and 63 species are known, yet of the whole bivalve fauna only 4 genera and 5 species pass to the Carboniferous series in North Devon, viz., *Aviculopecten granosus*, *A. plicatus*, *Pterinæa damnoniensis*, *Cucullæa Griffithii*, and *Curtonotus unio*. The Lower Devonian is even poorer, only 3 genera and 4 species occurring; these are *Aviculopecten polytrichus*, *Pterinæa anisota*, *P. spinosa*, and *Ctenodonta Kratchæ*. The last-mentioned bivalve is confined

to the Lower Devonian. The Middle Devonian is represented by 16 genera and 26 species—*Aviculopecten*, 2 species, *Pterinæa* 6, *Anodonta Jukesii*, *Cleidophorus ovatus*, *Corbula Hennahi*, *Cucullæa Hardingii*, *C. trapezium*, *Ctenodonta lineata*, *Leptodomus constrictus*, *Megalodon* 3, *Modiola scalaris*, *Pleurorhynchus* 2, *Pullastra antiqua*, and *Sanguinolaria elliptica*. *Megalodon*, *Pleurorhynchus*, *Corbula*, and *Cleidophorus* are essentially Middle Devonian. *Cucullæa*, *Curtonotus*, *Ctenodonta* are the chief genera in the Upper Devonian beds of North Devon, south of the latitude of Baggy Point. Few species pass to the Carboniferous south of Barnstaple and Pilton. The South Petherwin and Landlake beds in North Cornwall are Upper Devonian, and have yielded 65 species. They cannot be affiliated with the Carboniferous, the *Clymeniæ* and species of Orthoceratidæ forbidding it.

Any comparison of the insignificant British fauna with the splendid series of Devonian species in continental Europe and America is useless: no fewer than 90 genera and 900 species of Pelecypoda have been described; 260 being Monomyarian and 640 Dimyarian.

Gasteropoda.—Thirteen British genera and 45 species constitute the entire fauna of the Odontophora. *One species only occurs in the Lower Devonian.* The Middle contains the largest number of species (37), and 12 of the 13 genera, viz., *Acroculia*, *Euomphalus*, *Loxonema*, *Macrocheilus*, *Murchisonia*, *Natica*, *Nerita*, *Pleurotomaria*, *Scoliostoma*, *Trochus*, *Turbo*, and *Vermetus*. The Upper Devonian species are 17, and occur mostly in the Pilton, Brushford, and Petherwin areas. They represent 8 genera—*Acroculia*, *Euomphalus*, *Loxonema*, *Macrocheilus*, *Murchisonia*, *Natica*, *Platyschisma*, and *Pleurotomaria*. Five species pass to the Carboniferous—*Acroculia vetusta*, *Loxonema rugifera*, *L. tumida*, *Murchisonia angulata*, and *M. spinosa*.

The South Devon area has yielded 32 of the 37 Middle Devonian species, North Devon only 6, viz., *Euomphalus serpens*, *E. radiatus*, *Acroculia vetusta*, *Macrocheilus brevis*, *Natica*, and *Pleurotomaria*, with 11 Upper Devonian. The Petherwin beds in North Cornwall contain 7 Gasteropods, all Upper Devonian. (For a complete comparison of the two areas, see p. 181.)

Pteropoda.—One species, *Conularia*, has appeared in the Middle Devonian rocks of North Devon. Thirty species are known in Germany and America.

Heteropoda.—The order Nucleobranchiata through the Atlantidæ is represented in all three divisions of the Devonian rocks by *Bellerophon* (5 species) and *Porcellia* (3). *Bellerophon bisulcatus* occurs in the Lower and Upper divisions; *B. striatus*, Lower and Middle; *B. subglobosus*, *B. hiulcus*, and *B. Urii* in the Upper. The two latter range into the Carboniferous rocks. *Porcellia Woodwardi* and *P. striata* occur in the Middle Devonian of South Devon; *P. Symondsii* has hitherto only been found in the Upper (or Pilton and Barnstaple) beds south of Baggy. These 8 species have a wide range, due to their pelagic habit.

Cephalopoda.—*Clymenia*, *Cyrtoceras*, *Goniatites*, *Nautilus*, *Orthoceras*, and *Poterioceras*, are the 6 British genera with 60 species.

Clymenia.—Eleven species of this characteristic genus occur in the Devonian rocks of Britain, and all have been found in the Upper Devonian of Petherwin in North Cornwall. No *Clymenia* occur in the Devonian rocks of North Devon, either Middle or Upper.

Goniatites.—The Upper Devonian of Petherwin contains *G. biferus*, *G. linearis*, *G. subsulcatus*, *G. striatus*, and *G. vinctus;* 12 species occur in the Middle Devonian of Torquay; and in the Upper beds of North Devon, only *G. vincus* and *G. spirorbis.* Four of the Devonian species range into the Carboniferous rocks, the *G. carbonarius*, *G. excavatus*, *G. serpentinus*, and *G. subsulcatus?* As compared with the Carboniferous Goniatites, the Devonian group is of slight importance; in Britain alone 53 Carboniferous species are known.

Cyrtoceras.—With one exception the 13 species of this genus occur only in the Middle series at Torquay. The single departure from this is *Cyrtoceras rusticum*, known in the Petherwin beds.

Orthoceras.—Only one species of *Orthoceras* has yet occurred in the Lower Devonian, either in North or South Devon. The Middle group at Torquay has yielded 8 species, and the Upper in North Devon 13; and 4 of these North Devon forms pass to the Carboniferous south of Pilton and Barnstaple, viz., *O. cinctum*, *O. lineolatum*, *O. striatum*, and *O. undulatum.*

Nautilus.—We possess only 2 species, *N. germanus* and *N. megasipho;* the former Middle Devonian of Torquay, the latter Upper from Petherwin.

Pisces.—50 genera and 120 species range through the Old Red Sandstone. It can hardly be said that ichthyic life commenced prior to the commencement of the deposition of Old Red Sandstone. The few genera and species that made their appearance in the British seas at the close of the Silurian period, can only be traced into the very lowest beds of the Old Red in the Silurian area of Ludlow, Kington, and Ledbury, there scarcely passing beyond the passage group; we know them not higher in the system. In the North of Scotland, in the Orkneys, Caithness, and Cromarty area, the Lower Old Red Sandstone has furnished 18 genera and about 60 species; no prior stratigraphical relation or origin is known. They occur in that region, like the strata or rocks which contain them, fully developed and in vast numbers. Unlike the Old Red Sandstone of the Silurian area, the formation has there no fossiliferous base. The Silurian rocks are absent, the sandstones and conglomerates lying unconformably upon the metamorphic rocks. The only other organisms are Phyllopod and Eurypterid Crustacea, with the remains of 10 or 11 genera of plants.

Distribution of Pisces.—The results of researches into the distribution of the 49 or 50 genera and 120 species of fish through all the known deposits of Old Red in the British Islands seem to prove the absence of any Middle fish-bearing group, alike in England, Scotland, and Ireland. On palæontological grounds this fully confirms the most recent investigations as to the absence of the Middle Old Red Sandstone in Scotland and Ireland, and probably in the Welsh area also.

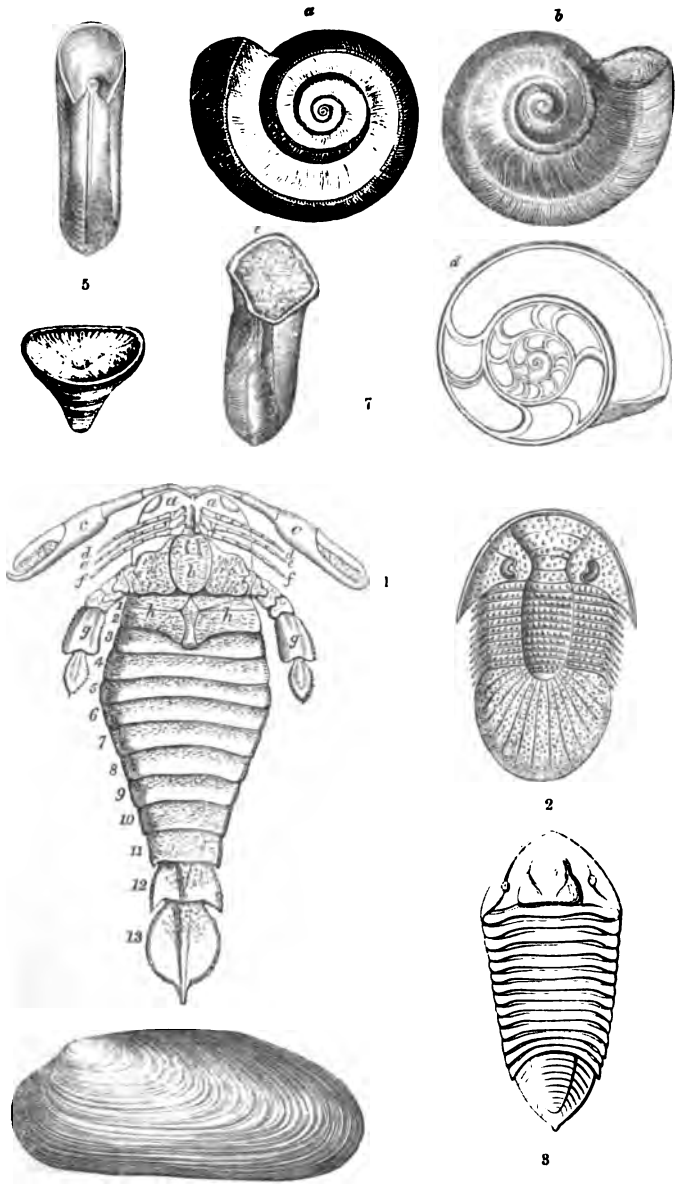
PLATE X.

DEVONIAN AND CARBONIFEROUS FOSSILS.

1. *Pterygotus anglicus* (Ag.) Lower Old Red Sandstone. Scotland. Ventral aspect after Dr. Woodward, F.R.S.
   - a. *The oval Carapace.* Showing sessile eyes at the anterior angles.
   - b. *The Metastoma.* (Post oval plate.)
   - c.c. *Antennules.* (Chelate appendages.)
   - d. *Antennæ*, or first pair of simple palpi.
   - e. *Mandibles.* Second pair of simple palpi.
   - f. *First Maxillæ.* Third pair of simple palpi.
   - g. *Swimming feet.* The serrated edges of the basal joints serve as *maxillæ.*
   - h. *Thoracic plate.* Covering the first two Thoracic segments.
   - 1–6. *Thoracic segments*, or Sommites.
   - 7–12. *Abdominal segments*, or Sommites.
   - 13. *Telson or Tail plate.*
2. *Bronteus flabellifer.* Middle Devonian.
3. *Homalonotus*, sp.
4. *Anodonta Jukesii.* Upper Devonian. Ireland.
5. *Clymenia lævigata.* Front view and Siphuncle.
6. *Calceola sandalina.* Middle Devonian.
7. *Euomphalus pentangulatus.* Carboniferous Limestone. a. Dorsal surface. b. Ventral surface. c. Pentagonal mouth. d. Section showing chambers.

PLATE X.

DEVONIAN AND CARBONIFEROUS FOSSILS.



Eight genera and 12 species of Elasmobranchii (Placoidei) range chiefly through the Lower Old Red—many with only 1 representative, viz., *Byssacanthus*, *Conchodus*, *Cosmacanthus*, *Ctenacanthus*, *Ctenoptychius*, and *Parexus*; also *Onchus* with 4 and *Ptychacanthus* with 2 species. The remaining 114 species represent 9 families and 41 genera, all Ganoidei :—

	Genera.	Species.
1. Cœlacanthini	2	2
2. Placodermi	3	10
3. Cephalaspidæ	15	40
4. Cheirolepini	1	4
5. Glyptodipterini	8	23
6. Saurodipterini	3	9
7. Ctenodipterini	2	2
8. Phaneropleurini	1	1
9. Acanthodæ	6	23
	41	114

Those genera that seem to specially characterise the Upper Old Red Sandstone, chiefly Scotch, are *Actinolepis*, *Asterolepis*, *Bothriolepis*, *Cosmacanthus*, *Dendrodus*, *Glyptolæmus*, *Glyptopomus*, *Holoptychius* (some species), *Homothorax*, *Lamnodus*, *Pamphractus*, *Phaneropleurus*, and *Phyllolepis*.

Of the entire British Devonian and Old Red fauna (577 species), 31 genera and 50 species pass to the Carboniferous.

TABLE XXIV.—*Distribution of the Devonian Fauna and Relation to Succeeding Carboniferous.*

From Ludlow.	Classes.	Genera.	Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Pass to Carboniferous.
	Plantæ?	18	27	$\frac{8}{11}$	$\frac{3}{4}$	$\frac{10}{16}$	$\frac{3}{3}$
	Protozoa	7	7	...	$\frac{1}{1}$	...	...
	Hydrozoa	...	...	...	...	...	...
	Actinozoa	25	55	$\frac{4}{4}$	$\frac{11}{11}$	$\frac{8}{8}$	...
	Echinodermata	14	28	$\frac{4}{8}$	$\frac{8}{13}$	$\frac{10}{10}$	$\frac{3}{6}$
$\frac{1}{1}$	Annelida	2	2	...	$\frac{1}{1}$	$\frac{1}{1}$	...
$\frac{3}{7}$	Crustacea	17	36	$\frac{6}{14}$	$\frac{6}{9}$	$\frac{10}{12}$	$\frac{1}{1}$
	Polyzoa	7	11	$\frac{3}{3}$	$\frac{6}{7}$	$\frac{3}{3}$	$\frac{1}{1}$
$\frac{2}{2}$	Brachiopoda	26	114	$\frac{13}{21}$	$\frac{14}{14}$	$\frac{14}{14}$	$\frac{1}{10}$
	Pelecypoda	23	63	$\frac{2}{2}$	$\frac{16}{16}$	$\frac{12}{12}$	$\frac{1}{1}$
	Gasteropoda	13	45	$\frac{1}{1}$	$\frac{13}{17}$	$\frac{8}{17}$	$\frac{1}{1}$
	Pteropoda	1	1	...	$\frac{1}{1}$	...	...
	Heteropoda	2	8	$\frac{2}{2}$	$\frac{2}{2}$	$\frac{2}{2}$	$\frac{1}{1}$
$\frac{1}{6}$	Cephalopoda	6	60	$\frac{1}{1}$	$\frac{6}{11}$	$\frac{6}{11}$	$\frac{1}{1}$
	Pisces	50	120	$\frac{24}{31}$	$\frac{3}{3}$	$\frac{10}{13}$	...
$\frac{14}{19}$	.....	211	577	$\frac{80}{180}$	$\frac{109}{179}$	$\frac{103}{117}$	$\frac{31}{50}$

TABLE XXV.—*Organic Remains of the Middle Palæozoic or Devonian and Old Red Sandstone.*

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.[1]	Locality.
PLANTÆ.					
Filicinæ—					
Adiantites	1	...	...	1	Ireland.
Caulopteris	1	1	...	..	Thurso.
Cyclopteris	1	1	...	...	,,
Filicites	1	...	...	1	...
Palæopteris	1	...	...	1	Ireland.
Sphœnopteris	2	...	...	2	,,
Trichomanites	1	1	...	1	...
Coniferæ—					
Araucaryoxylon	1	1	...	...	...
Coniferous Wood	3	2	2	...	Wick.
Pinnularia	1	1	...	...	,,
Lycopodiaceæ—					
Cyclostigma	1	...	...	1	Ireland.
Knorria	1	...	...	1	,,
Lepidodendron	1	1	1	...	...
Lycopodites	1	1	...	...	...
Psilophyton	2	2	2	...	Wick.
Sagenaria	5	...	...	5	Ireland.
Stigmaria	1	...	...	1	...
Calamites	2	...	...	2	...
18	27	11	5	16	
PROTOZOA.					
Rhizopoda—					
Scyphia	1	...	1	...	South Devon.
Sphærospongia	1	...	1	...	,,
	2	...	2	...	
Hydro-Corallinæ—					
Stromatopora	5	...	5	...	South Devon.
CŒLENTERATA.					
Actinozoa—					
Acervularia	7	...	7	...	South Devon.
Alveolites	4	1	4	...	S. and N. Devon.
Amplexus	1	...	1	1	,,
Battersbyia	1	...	1	...	,,
Calceola	1	...	1	...	,,
Campophyllum	1	...	1	...	,,
Chonophyllum	1	...	1	...	,,
Cyathophyllum	11	1	11	2	,,
Cystyphyllum	2	...	2	...	,,
Emmonsia	1	...	1	...	,,
Endophyllum	2	...	2	...	,,
Favosites	5	1	5	...	,,
Fistulipora	1	...	1	1	South Devon.
Hallia	1	...	1	...	,,
Heliolites	1	...	1	...	,,

[1] The general term "Devonian" also includes the Old Red Sandstone. For many characteristic Devonian species, see plates 8, 9, 10.

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Locality.
Heliophyllum	1	...	1	...	South Devon.
Metriophyllum	1	...	1	...	„
Michelinia	1	...	1	1	„
Pachyphyllum	1	...	1	...	„
Petraia	4	4	2	2	S. and N. Devon.
Pleurodictyum	1	1	1	...	South Devon.
Smithia	3	...	3	...	„
Spongophyllum	1	...	1	...	„
Strephodes	1	...	1	...	„
Syringophyllum	1	...	1	...	„
25	55	8	53	7	

ANNULOIDA.

Class—ECHINODERMATA.

Crinoidea—					
Actinocrinus	2	1	1	1	North Devon.
Adelocrinus	1	...	...	1	„
Cupressocrinus	2	...	2	...	South Devon.
Cyathocrinus	8	2	3	5	„
Hexacrinus	3	...	3	...	„
Platycrinus	2	...	2	...	North Devon.
Poteriocrinus	1	...	...	1	„
Rhodocrinus	1	...	...	1	„
Taxocrinus	1	...	...	1	„
Asteroidea—					
Helianthaster	1	...	...	1	„
Palæster	2	...	...	2	„
Protaster	2	...	...	2	„
Blastoidea—					
Pentremites	1	...	...	1	S. and N. Devon.
Cystoidea—					
Echinosphærites	1	...	1	...	South Devon.
14	28	3	12	16	

ANNULOSA.

Class—ANNELIDA.

Serpula	1	...	...	1	S. Wales in O.R S.
Tentaculites	1	...	1	...	N. and S. Devon.
	2	...	1	1	

Class—CRUSTACEA.

Limulidæ—					
Belinurus	1	...	...	1	S. Devon, Ireland.
Eurypteridæ—					
Eurypterus	6	6	...	...	Scotland.
Pterygotus	6	6	...	1	Scotland, Ireland.
Stylonurus	6	6	...	1	Worcestershire.
Trilobita—					
Bronteus	1	...	1	...	South Devon.
Calymene	1	...	1	1	South Devon. Petherwin, and Croyd.

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Locality.
Cheirurus	1	...	1	...	South Devon.
Harpes	1	...	1	...	"
Homalonotus	1	1	...	...	"
Phacops	5	2	4	4	S. and N. Devon.
Phillipsia	1	...	1	1	"
Phyllopoda—					
Dithyrocaris	1	...	...	1	Scotland.
Estheria	1	1	...	...	"
Ostracoda—					
Cypridina	1	...	...	1	North Devon.
Parka	1	1	...	1	Scotland, &c.
Prearcturus	1	1	...	...	Worcestershire.
Proricaris	1	...	...	1	Ireland.
17	36	24	9	13	

MOLLUSCOIDA.

Class—POLYZOA.

Ceriopora	2	...	1	1	North Devon.
Fenestella	4	1	3	3	S. and N. Devon.
Glauconome	1	...	...	1	North Devon.
Hemitrypa	1	...	1	...	South Devon.
Polypora	1	...	...	1	North Devon. Cornwall.
Ptylopora	1	...	1	...	South Devon.
Retepora	1	1	1	...	"
	11	2	7	6	

Class—BRACHIOPODA.

Athyris	8	...	5	3	South Devon, Petherwin.
Atrypa	6	3	6	2	"
Camarophoria	1	...	1	...	South Devon.
Chonetes	5	3	2	1	S. and N. Devon.
Crania	1	1	1	...	South Devon.
Cyrtina	4	...	4	1	"
Davidsonia	1	...	1	...	"
Discina	4	3	3	1	"
Leptæna	4	1	3	...	South Devon, Cornwall.
Merista	1	...	1	...	South Devon.
Lingula	5	5?	...	1	North Devon.
Nucleospira	1	?	?	?	South Devon.
Orthis	7	3	5	1	S. and N. Devon.
Pentamerus	2	...	2	...	South Devon.
Productus	5	...	1	5	S. and N. Devon.
Rensselæria	1	...	1	...	"
Retzia	1	...	1	...	"

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Locality.
Rhynchonella	22	4	20	5	S. and N. Devon.
Spirifera	19	3	14	8	,,
Spiriferina	2	1	2	1	,,
Streptorhynchus	6	3	3	3	,,
Stringocephalus	1	...	1	...	,,
Strophalosia	1	...	1	1	,,
Strophomena	1	1	1	1	,,
Terebratula	4	...	3	2	,,
Uncites	1	...	1	...	,,
26	114	31	83	36	

MOLLUSCA.

Class—PELECYPODA.

Aviculopecten	10	1	2	9	S. and N. Devon.
Pterinæa = Avicula	10	2	6	6	,,
Cardiola	1	...	...	1	,,
Anodonta	1	...	...	1	Ireland.
Clidophorus = Nucula	1	...	1	...	South Devon.
Corbula	1	...	1	...	,,
Conocardium = Pleurorhynchus	2	...	2	...	North Devon.
Cucullæa	6	...	2	6	,,
Curtonotus	6	...	...	6	South Devon.
Ctenodonta	5	1	1	4	North Devon.
Cypricardia	1	...	...	1	,,
Edmondia	1	...	...	1	,,
Leptodomus	1	...	1	1	,,
Megalodon	3	...	3	...	S. and N. Devon.
Modiola	2	...	1	1	,,
Myalina	1	...	1	...	,,
Mytilus	2	...	1	2	,,
Orthonota	1	...	1	1	South Devon.
Pullastra	2	...	1	2	,,
Sanguinolaria	2	...	1	2	North Devon.
Sanguinolites	2	...	...	2	,,
Schizodus = Axinus	1	...	1	1	S. and N. Devon.
Venus	1	...	...	1	North Devon.
23	63	4	26	48	

Class—GASTEROPODA.

Acroculia	3	...	3	1	S. and N. Devon.
Euomphalus	5	...	5	1	,,
Loxonema	8	...	5	4	South Devon.
Macrocheilus	6	...	6	1	S. and N. Devon.
Murchisonia	5	...	4	2	South Devon.
Natica	2	...	1	2	S. and N. Devon.
Nerita	1	...	1	...	South Devon.
Platyschisma	1	...	...	1	North Devon.
Pleurotomaria	8	1	6	5	S. and N. Devon.
Scoliostoma	1	...	1	...	South Devon.
Trochus	1	...	1	...	,,
Turbo	2	...	2	...	,,
Vermetus	2	...	2	...	,,
13	45	1	37	17	

PTEROPODA.

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Locality.
Conularia . . .	1	...	1	...	North Devon.

HETEROPODA.

Bellerophon . . .	5	2	1	4	S. and N. Devon.
Porcellia . . .	3	1	2	2	„
	8	3	3	6	

Class—CEPHALOPODA.

Clymenia . . .	11	...	...	11	Cornwall, S. Devon.
Cyrtoceras . . .	13	...	12	1	South Devon.
Goniatites . . .	18	...	12	6	S. and N. Devon.
Nautilus . . .	2	...	1	1	Petherwin and S. Devon.
Orthoceras . . .	15	1	8	13	S. and N. Devon.
Poterioceras . . .	1	...	...	1	South Devon.
6	60	1	33	33	

VERTEBRATA.

Class—PISCES.

Acanthodes . . .	4	4	...	...	Elgin, Caithness.
Actinolepis . . .	1	...	...	1	Elgin.
Asterolepis . . .	1	1	...	1	Elgin, Caithness.
Auchenaspis . .	2	2	...	...	Worcestershire.
Bothriolepis . . .	1	...	...	1	Elgin, Nairn, Ireland.
Brachyacanthus = Climatius	...	...	...	...	...
Byssacanthus . .	1	1	...	...	Herefordshire.
Cephalaspis . . .	2	2	...	...	Herefordshire, Forfar.
Cheiracanthus . .	6	6	...	...	Orkney, Gamrie, Cromarty.
Cheirolepis . . .	4	4	...	...	Orkney, Cromarty, Caithness.
Climateus . . .	3	3	...	...	Balruddery.
Coccosteus . . .	6	6	...	...	Orkney, Cromarty, Caithness.
Conchodus . . .	1	...	...	1	Seat-Crag.
Cosmacanthus . .	1	...	...	1	Elgin.
Ctenacanthus . .	1	1	...	...	South Wales.
Ctenoptychius . .	1	...	1	...	Scotland.
Cyathaspis . . .	1	1	...	...	Worcestershire.
Dendrodus . . .	4	...	...	4	Morayshire.
Didymaspis . . .	1	1	...	...	Worcestershire.
Diplacanthus . .	6	6	...	...	Morayshire, Orkney, Caithness.
Diplopterus . . .	3	3	...	...	Orkney, Caithness, Gamrie.
Dipterus . . .	1	1	...	...	Orkney, Caithness.
Eucephalaspis . .	5	4	1	...	...
Eukeraspis . . .	1	1	...	...	...
Euthacanthus . .	1	1	...	...	...
Glyptolæmus . .	1	...	...	1	Dura Den.
Glyptolepis . . .	3	3	...	?	Elgin, Ireland?
Glyptopomus . .	2	...	...	2	Perthshire.

Genera.	No. of Species.	Lower Devonian.	Middle Devonian.	Upper Devonian.	Locality.
Gyroptychius . .	2	2	...	...	Orkney.
Hemicyclaspis . .	1	1	...	...	...
Holaspis . . .	1	1	...	...	...
Holoptychius . . .	4	1	...	4	Orkney, Elgin, Perth, Brecon.
Homothorax . . .	1	...	...	1	Perthshire.
Ischnacanthus . .	1	1	...	...	...
Lamnodus . . .	3	...	...	3	Elgin.
Onchus	4	4	...	...	Herefordshire, &c.
Osteolepis . . .	5	5	...	...	Orkney, Caithness.
Pamphractus . . .	1	...	...	1	Perthshire.
Parexus	1	1	...	...	Balruddery, Caithness.
Phaneropleuron . .	1	...	...	1	Dura-Den.
Phyllolepis . . .	1	...	...	1	Clashbinnie.
Placothorax . . .	1	1	...	...	Elgin.
Platygnathus . . .	2	1	...	1	Orkney, Perthsh.
Pterichthys . . .	12	8	...	4	Orkney, Cromarty, Caithness, Ireland.
Pteraspis . . .	6	6	...	...	Orkney, Perthsh.
Ptychacanthus . .	2	2	...	...	Herefordshire, Monmouthshire.
Scaphaspis . . .	4	4	...	...	,,
Tripterus . . .	1	1	...	...	Orkney.
Tristichopterus . .	1	1	...	...	Caithness.
Zenaspis . . .	1	1	...	...	Herefordshire.
50	120	92	2	28	

PART III.

UPPER PALÆOZOIC STRATA.

CHAPTER XXI.

THE CARBONIFEROUS SYSTEM.

Divisions of the System.—In England the Carboniferous system, when fully expanded, admits of division into the following six groups, which, however, are not to be found together in every district:—

Coal measures Millstone grit	Upper Group.
Yoredale rocks Scar limestone Lower limestone shales Calciferous sandstone	Lower Group.

These six groups are naturally arranged into two greater divisions, the upper one specially coal-bearing, or Carboniferous proper, the lower calcareous, in places arenaceous; but in each of the many districts of Britain where these strata occur, some local peculiarity is observable which often disturbs this general classification. The millstone grit is connected through its marine fauna with the Yoredale rocks in the north of England, and with the coal measures through its plants, and thus has the aspect of a transition group, which may for convenience be sometimes joined to the lower, sometimes to the upper series, or occasionally be treated alone. In Yorkshire, the limestone series is intermingled with coal, sandstones, and shales; in the northern parts of Northumberland, these two series are intimately blended. The millstone grit is 800 feet thick in Yorkshire and Derbyshire, but thins away in the south-west of England.

There is nothing peculiar in this: similar phenomena occur among the higher or newer formations. In fact, it is certain that among all the groups of strata the minute distinctions are mostly local, and even the formations themselves, however extensive, are limited within exact and well-defined conditions. The Carboniferous series in Britain is, with few exceptions, conformable to the Old Red Sandstone below.

In describing this series, we shall confine ourselves principally to the British Islands, it being far too extensive a subject to be treated generally.

The following are the chief *local* subdivisions occurring in the Carboniferous rocks, and illustrate the general distribution through England and Wales :—

TABLE XXVI.—*Subdivisions of Carboniferous Rocks.*

1. *Northumberland and Durham.*

Coal Measures (1500 to 2000 feet).	Upper coal measures with *thin* coals.
	Middle coal measures with *thick* coals.
	Lower coal measures or Gannister beds[1] with *thin* coals.
Millstone grit (400 feet.)	Alternations of grit and shale.
Yoredale rocks and Carboniferous limestone series (*Bernician*).[2]	Alternations of limestone, coal, shale, grit, and sandstone.
Tuedian beds.	White or pale brown and grey sandstones and greenish grey shales, cement stones and impure limestones.

2. *Lancashire, Yorkshire, and Derbyshire.*

Coal measures (2000 to 7000 feet).	Upper coal measures with thin limestones and coals.	
	Sandstones.	
	Middle coal measures with *thick* coals.	
	Lower coal measures or Gannister beds[1] with *thin* coals.	
Millstone grit (300 to 3000 feet). Yorkshire and Derbyshire.	Rough rocks (first grit)	50 to 60 feet.
	Shales	
	Haslington flags (second grit)	60 to 100 ,,
	Shales	75 to 150 ,,
	Middle grits and shales (third grit)	100 to 175 ,,
	Shales and sandstones	300 to 500 ,,
	Kinder Scout grit (fourth grit)	500 to 700 ,,
Yoredale rocks (300 to 2000 feet).	Shales.	
	Yoredale grit.	
	Shale, with hard thinly-bedded Yoredale sandstones in places.	
	Black shales with thin earthy impure limestones.	
Carboniferous limestone (400 to 1200 feet).		

3. *South-West of England and South Wales.*

Coal measures (5000 to 12,000 feet.	Upper coal measures.
	Pennant grit.
	Lower coal measures.
(300 to 1000 feet).	Millstone grit or "*Farewell Rock.*"
(1000 to 3000 feet).	Upper limestone shale.
	Carboniferous limestone.
(300 to 500 feet).	Lower limestone shale.

[1] *Gannister* or *Calliard*, a term used to designate a hard siliceous bed, constituting the floor of some of the Durham and Yorkshire coal-seams.

[2] *Bernician*, a name suggested by Mr. G. A. Lebour, from the circumstance that no Yoredale rocks proper and no scar limestone proper are known to occur in these beds. (*See further*, p. 248.)

Geographical Distribution of the Carboniferous Rocks in England and Wales.

The great and connected Carboniferous series of Tweeddale, Northumberland, Durham, Yorkshire, Derbyshire, and Nottinghamshire, spreads westward to Cheshire, Lancashire, Westmoreland, and Cumberland, a district or area nearly 200 miles in length and, on the average, 60 miles in breadth.

In it most, if not all, of the divisions already stated may be recognised, under varying conditions.

A long, but narrow and broken, band of the Carboniferous system is traced from Anglesea, by the Great Orme's Head, the sides of the Vale of Clwyd, and the country of Halkin, Mold, and Wrexham, to Oswestry, and from thence we may pass by the detached coalfields of Shrewsbury, Coalbrook Dale, Billingsley, the Clee Hills, Dudley, Coventry, to the Ashby-de-la-Zouch coalfield. These coalfields appear now separated at the surface by the outlying New Red Sandstone, but they were and probably are one physically connected below. In none of these districts is the series of rocks so thick or so varied as in the larger tract to the north. The fullest development is in Flintshire, where the limestone is succeeded by the millstone grit, and the coal series in succession.

Farther south, we have the great range of the Carboniferous strata in South Wales, extending from St. Bride's Bay in the west to Pontypool in the east, about 90 miles, but interrupted by the Old Red Sandstone (on which the whole rests), at the mouths of the Towy and the Taf. The breadth, at a maximum, is about 20 miles. The series consists of the following divisions in the extreme west of the district:—

Coal measures	11,000 feet thick.
Millstone grit	300 „ „
Carboniferous limestone	1,900 „ „
Lower shales, &c.	500 to 800 „ „

Separated about 20 miles by Old Red Sandstone, we have the Dean Forest coalfield. The series is subdivided as in South Wales, but is nowhere so thick in any part.

Coal measures	2765 feet.
Millstone grit	270 „
Yoredale series	146 „
Carboniferous limestone	480 „
Lower limestone shales	165 „

Similar remarks apply to the considerable coalfield in Gloucestershire, north of Bristol, which is continued across the Avon into Somersetshire. The Avon section at Bristol gives us the following general succession:—

Coal	—
Millstone grit	950 feet.
Yoredale beds	400 „
Carboniferous limestone	1438 „
Lower limestone shales, &c.	500 „
	3288 feet.

We can give no accurately measured section of the peculiar Carboniferous system of North Devon, where in general terms we have the following series:—

Culm and sandstone, with impure anthracite coal.
Thick shales and thin dark limestones without fossils.

The district stretches 50 miles from east to west, and from north to south 35 miles, occupying on the whole a broad, much undulating, and contorted synclinal, composed of flaggy sandstones and grit, containing few or no traces of coal above the thin coal seam at Bideford.

Carboniferous Limestone and Millstone Grit Series.

(*A.*)—*Carboniferous or Mountain Limestone Formation.*

Great Scar (Scaur) Limestone of Sedgwick.

The history of the carboniferous limestone must be studied within the limits of the British Islands, for in no other region is it so extensively or so variously developed. Its romantic rocks border many of the most beautiful valleys of the south-west of Scotland, northern and central England, and encircle the wide and older Palæozoic regions of Wales.[1] In Ireland this limestone is the prevalent and characteristic rock in most of the counties, except Derry, Antrim, and Wicklow.

The romantic channel of the Meuse in Belgium runs for a considerable distance about Namur and Liége through a very remarkable and grand range of carboniferous limestone, along the northern side of the primary slates of the Ardennes, prolonged eastward to the German side of the Rhine near Düsseldorf, and continued westward to the north of France, beneath a wide deposit of cretaceous rocks in the neighbourhood of Boulogne. The coal-fields of the centre and south of France, of Saarbrück, Saxony, and Silesia, &c., appear to be devoid of this rock; but it occurs in Poland, in the north-east of Bavaria, and in Bohemia. It is also greatly developed in North America, supporting the ordinary bituminous and anthracite coal.

The carboniferous limestone presents a very different aspect in the northern and western counties of England. In Somersetshire, Gloucestershire, South Wales, North Wales, Derbyshire, and Leicestershire, this rock appears as an immense, nearly undivided, calcareous mass, in places perfectly defined below by the Old Red Sandstones or Silurian strata which support it, and as distinct above by the abrupt covering of sandstones and shales which accompany the coal.

The Cambrian slates are surrounded for three quarters of a circle, from Egremont to Ulverstone, by a belt of this limestone, which reposes indiscriminately upon the Lower Silurian rocks near Loweswater, the Middle series near Ulswater, the Upper Silurian series from Shap to Ulverstone, and the Old Red conglomerate at the several points of Dacre, Sedbergh, Barbon, Kirkby Lonsdale, and Ulverstone.

The grand natural section at Ingleborough and Penyghent presents us with the following succession:—

[1] See the Maps of the Geological Survey of Great Britain and Ireland.

			Feet.
	Group above the scar limestone (millstone grit series)	Alternations of sandstone and shale, with bad coal on Penyghent	100
		Millstone grit of Ingleborough	60
		Alternations of sandstone and shale	100
Yoredale Beds.	Upper limestone.	Thin limestone 8 feet; Shale 10 ,,; Main limestone 60 ,,; Great limestone	78
		Alternations principally of shales and sandstones, some of them flagstones with thin limestones	300
		Great scar limestone with calcareous conglomerate beds at bottom	400

This series rests on slate rocks of Silurian age.

Northward from Ingleborough in Wensleydale or Yoredale the following modified section occurs:—

			Feet.
	Millstone grit series.	Coarse and fine sandstones, shales, and COAL; Coarse, fine, and slaty sandstones, shales, cherty beds, and COAL; Millstone grit of Ingleborough, shales, chert beds, and COAL	700
Yoredale Beds.	Upper limestone.	Thin limestone, sandstone, shale; Main or twelve-fathom limestone; Shales, sandstones, and COAL, underset limestone	200
	Flagstone series.	Alternations of flagstones of various quality, in great abundance, with shales, COAL, hard gritstones, and three or four masses of limestone, from 6 to 30 feet thick. The black marble of Dent is nearly at the base of this group.	500
	Scar limestone.	Limestones of great thickness, with partings principally of shale.	500

The series is incomplete, other limestones existing below.

Here the millstone grit has become divided into distinct parts; and the calcareous portions of the upper limestone (Yoredale series) are also better defined and more important; the scar limestone has assumed the character of a double belt, which henceforward distinguishes it for a great distance to the northward.

The following section occurs in Swaledale:—

					Feet.
	Millstone grit series.	Coarse gritstones, shales, finer sandstones, shales, and COAL	600		800
		Variable series of thick shales, with sandstones and COAL, and local interpolations of limestone and chert	200		
Yoredale Beds.	Upper limestone.	Limestone		3	352
		Shale, &c.		63	
		Main or twelve-fathom limestone		72	
		Grit, chert, shale, and COAL		96	
		Underset lime		18	
	Flagstone series.	Variable alternations of gritstone, flagstone, and plate, with three or four limestones from 6 to 30 feet thick			340
	Scar limestone.	Of great thickness, but only partially exposed in the bottom of Swaledale.			

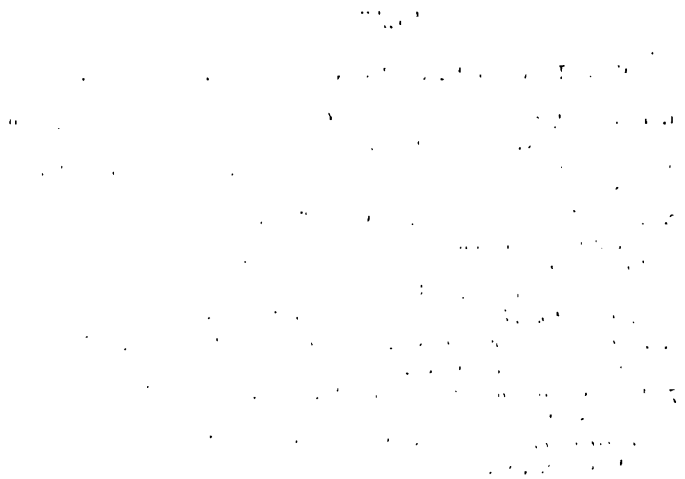


PLATE XI.

FOSSILS OF THE CARBONIFEROUS LIMESTONE.

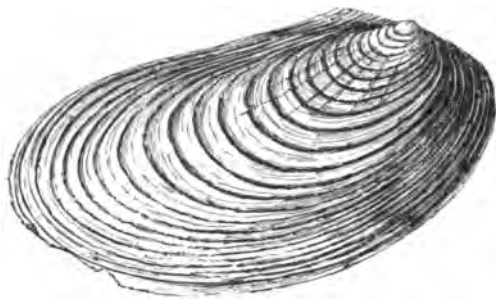
1. *Posidonomya lateralis* (Sow.) Carboniferous Limestone. Venn, Trescot, &c. North Devon.
2. *Posidonomya Becheri* (Goldf.) Carboniferous Limestone. Swimbridge North Devon.
3. *Edmondia sulcata* (Phill.) Carboniferous Limestone. Yorkshire, Derbyshire, Ireland, &c.
4. *Euomphalus pentangulatus* (Sow.) Carboniferous Limestone. Yorkshire, Northumberland, &c.

5*a–d*. *Pleurotomaria aspera* (Sow.) Carboniferous?

6. *Pleurotomaria carinata* (Sow.) Carboniferous Limestone. Yorkshire, Derbyshire, Ireland, &c.
7. Tooth of *Megalichthys Hibberti* (Ag.) Lower Carboniferous. Burdie House, Leeds, &c.
8. *Orthoceras undulatum* (Sow.) Carboniferous Limestone. Derbyshire, Lancashire, &c.

PLATE XI.

FOSSILS OF THE CARBONIFEROUS LIMESTONE.



1

8

4

5

6

3

7

2

It is possible that this section does not show us the full thickness of the series.

The Millstone Grit and Yoredale Rocks have now become more complicated, and require further division, as compared with the Ingleborough section, leading to the still more developed series of Teesdale and Aldstone Moor, where the scar limestone and its associated shales are 1000 feet thick, the flagstone series and the upper limestone (Yoredale beds) 400 feet, and the millstone grit 700 feet thick.

Range of the Carboniferous Limestone.—The great or "scar limestone" series passes westward from Ingleborough by Kirkby Lonsdale, Burton, and Cartmell to Ulverstone and Dalton; extending northward to Kendal.

Gordale Scar, near Settle. In scar limestone.

On the south of Ulverstone it is covered by the "*intermediate grit and plate series*" (Yoredale beds), with traces of coal; and a more extensive deposit of this kind south of Kirkby Lonsdale, yielding useful coal and flagstone, is again overlaid by the Yoredale limestone and afterwards by the millstone grit series towards Lancaster.

Omitting the irregular interpolations of igneous rocks, called "toadstone," we have the scar limestones more than 750 feet thick, surmounted by shale, with their alternations of sandstones, *limestones*, ironstones, &c., 500 feet, and the hills crowned by bold ranges of millstone grit, and its accompanying sandstones, 360 feet in thickness.

Range South of Derbyshire.—South of Derbyshire we have no longer the same remarkable masses of Yoredale shales and millstone

grit interposed between the scar limestones and the true carboniferous sandstones and shales. The limestone occurs in North Wales (Anglesea), across the centre and on the northern coast near Beaumaris, and on the Menai Strait. It forms the conspicuous promontory of the Great Orme's Head, passes under Denbigh and Ruthin on the western side of the vale of Clwyd, thence forming the picturesque and elevated country west of Holywell, Mold, and Wrexham, comprising the magnificent cliffs of Eglwyseg overlooking the beautiful Vale of Llangollen, and continuing its course southward to an almost sudden termination at Llanymynach, near Oswestry. In this range there is only a narrow trace of Old Red Sandstone (seen below, as in the cliffs of Eglwyseg), and a trace also south of Denbigh. This whole range represents the scar limestone.

Slightly exhibited under the coal of the Clee Hills, it resumes its grandeur on the edge of the Forest of Dean, there disclosing beneath it the lower limestone shales, as well as the millstone grit group all around the forest. The following is a short summary as seen in the Forest of Dean :—[1]

Coal measures.		
Millstone grit, consisting of sandstone, shale, and conglomerate.		
Grey and red limestone and marls	25 feet	200 feet.
Red sandstone, with thin shales and marls, some hæmatite veins	176	
Scar limestone, red, grey, and blue, with hæmatite ore	480	
Lower group of shales and limestones, mostly dark, with remains of fishes (Lower Limestone shales)	165	

The upper part of the Old Red series is composed of the grey, yellow, and red sandstones and marls, with scatterings of quartz pebbles, &c. Plants analogous to some in North Devon occur in this series. On the Avon at Bristol it is thicker.

South Wales.—Round a great part of the South Wales coal-field we find the Lower Limestone Shale rising to importance, and continually thickening to the westward; so that, in the district of Gower, a part of Pembrokeshire, its thick shales and thin limestones constitute great cliffs and scars, full of fossils resembling those of the Upper Devonian series. In Ireland, especially in the southern parts, this analogy is still more apparent and extensive.

South Wales Coal Field.—In still greater thickness the carboniferous limestone groups pass round the "basin" of the South Wales coal-field, under the "millstone grit," and over the Old Red Sandstone. At the western extremity of the range, and on the south side (West Angle Bay), we find, through the work of the Geological Survey, the lower series to consist of reddish and yellowish shales, limestones, and sandstones, in many alternations, 584 feet thick. The whole group is marked at frequent intervals by beds of coprolites and *fish-remains*, and near the bottom are remains of plants. In Caldy Island, also on the south side of the "basin," the scar limestone, the lower shales and Old Red Sandstone appear in magnificent cliffs, and disclose the whole

[1] De la Beche, Memoirs of Geological Survey, vol i., p. 127.

series of organic and mechanical deposits. This limestone is almost unmixed with any sedimentary matter and is 1895 feet thick, the lower beds, from 400 or 500 feet, being literally full of *crinoidea* and *brachiopoda*, and the upper, 1400 or 1500 feet, exhibiting, besides other fossils, distinct *coral* beds, resembling reefs. The lower series is here, as at Caldy Island, very rich in remains of fish, crinoidea, and brachiopoda.[1]

If we now add to these sections the known thicknesses of the superincumbent strata corresponding to the millstone grit and coal measures, we shall have the following general section of the carboniferous system in South Wales :—

Coal measures—no limestone	11,000 feet.
Millstone grit (called Farewell Rock) &c. (plants)	300 „
Yoredale rock? (Gower shales)	1,600? „
Scar limestones (corals, &c.)	1,900 „
Lower limestone shales (bone beds, &c.) (a few plants)	400 „
	15,200 „

Or more than two and a half miles in thickness.

The thickness here assigned, however, is not attained by any one member of the group in every part of the basin or its borders. The limestone series, in particular, is considerably reduced on the north side of the basin, and as a whole, the series grows thinner toward the east. Perhaps it is thickest in all particulars about Swansea and in the picturesque district of Gower, where in a limited tract the Yoredale shales appear to have a thickness of 1600 feet.[2]

Bristol Section.—The section of lower carboniferous strata on the Avon, near Bristol, has been long known as the best in the south-west of England, and has been often measured and described. The most detailed account of the thicknesses is contained in the Geological Survey's Memoirs.[3] In general terms it may be thus described :—

Millstone grit—mostly a hard, reddish grindstone, fine-grained, much resembling quartzite	950 feet.
Alternations of limestone, red or grey, compact or granular, with shales, red, dark, or grey, and *sandstones*, red or grey. Fossils through a great part of the mass. *Producta gigantea* abundant near the base. The limestone in places oolitic, coraliferous, and foraminiferal	about 400 „
Scar limestones—grey, reddish, mottled, brown and black, compact, shelly, crinoidal, and oolitic, in beds varying in thickness and partially divided by *shales*	1438 „
Lower series (lower limestone shale), with many alternations of limestones and shales, the former often black, brown, yellowish, sometimes impure, and the lower part charged with fish remains and cyprides in abundance (the "bone bed" resting on the Old Red Sandstone)	500 „

The upper part of the Old Red Series shows yellow and grey sandstones and marls, with scattered pebbles, and is sparingly conglomeratic.

[1] De la Beche, *op. cit.* [2] De la Beche, *op. cit.*
[3] Vol. i. p. 113.

Mendip Hills.—Proceeding southward from the Bristol district, we may notice the limestone series in the Mendip Hills at Chedder Cliffs, on an anticlinal axis, which displays the nucleus of the Old Red Sandstone; these cliffs are grand in the extreme. The upper part of the series not being well seen, we have the following section:—

Scar limestone, in many parts very cherty, the chert being in nodules of irregular form, and lying in the midst of the beds of limestone, which assume various colours, and are, as at Bristol, often oolitic. Corals often cherty. Hæmatite also occurs as veins and pockets in the limestone of Bristol and Dean Forest.
Lower series of shales with thin limestones (lower limestone shales).

Thus, from the Tweed and the mountains of Northumberland to the precipices of the Avon and Mendips, we have traced the course of the Carboniferous system, and have seen the changes of the much-varying bed of the sea over that large area. South of the Mendips, near Bideford and Barnstaple, we enter quite a different local series of carboniferous beds, with little coal and little limestone; a series as unlike the great carboniferous groups of the other side of the Bristol Channel, in S. Wales, as is the Devonian type of Old Red sandstone of Devon to the Old Red of Breconshire and Scotland.

North Devon.—The series of carboniferous deposits in North Devon about Barnstaple and Bampton has the following general aspect:—

Lower part, anthracitiferous, and containing ironstone, and by these characters agreeing with the coal deposits of Pembrokeshire. This is in general a gritstone series, with plants of the coal formation.
Coddon hill grits, cherts, and shales of considerable but variable thickness (millstone grit).
Limestone and black shale, with posidoniæ, goniatites, &c.
Black shale group—possibly the equivalent of the lower limestone shales.

South Devon.—Similar in general character is the series in South Devon about Trescott and Low Trenchard:—

The gritstone group of Central Devon.
Upper shale group—dark shales, carbonaceous grits and shales, equal to the Coddon Hill series, which are probably millstone grit.
Calcareous group—limestone of dark colour, and irregular bedding with shales (*Posidonomyæ*).
Lower shale group, with few fossils and no cleavage.

Having thus compared in the most general way the component groups of the carboniferous limestone and millstone grit series in different localities, and shown the variation which they have undergone, it may be well to describe some of the principal characters or features of these several groups.

Scar Limestones.

Physical Character.—The carboniferous limestone, though by no means of one uniform aspect or chemical composition, possesses, nevertheless, a certain facies of mineralogical characters which are scarcely to be recognised in any of the succeeding secondary calcareous deposits.

It is usually a nearly pure carbonate of lime, of a greyish or very grey-blue tint, of considerable hardness, and imperfect conchoidal fracture. Some of the varieties are very dark, and even quite black (Swansea, Abergavenny, Kilkenny, Derbyshire, Yorkshire), but the latter commonly contain a minute admixture of argillaceous and bituminous matter. Many varieties exhale a fetid odour on being rubbed or bruised. In Derbyshire, and generally along the Yorkshire and Westmoreland ranges, the scar limestones contain considerable beds of a granular and even brecciated limestone capable of being employed as good freestone, and some beds in Derbyshire and Westmoreland appear almost wholly composed of crystalline grains, and contain magnesia. The lower layers, which rest upon the slate in the Craven mountains at Kendal and near Penrith, are filled with large and small boulders of the slate, so as to become a true conglomerate.

Fauna.—But the most decided characters of these rocks are the organic remains, all of which are different from those of the strata above or below. The prodigious abundance of Brachiopoda (*productæ, spiriferæ*, &c.) and other shells, rugose or lamellated corals, and above all, crinoidal remains, will almost always enable the student to identify at once this division of the carboniferous limestone. The crinoidea in particular are so excessively abundant in certain parts as to constitute fully three-fourths of the mass of the rock, which is greatly used for economical purposes.[1]

Chert Beds and Nodules.—A remarkable character is imparted to certain beds seen in the vertical sections of this rock in the Mendip Hills, in several parts of Derbyshire, South Wales, and the neighbourhood of Clitheroe, by nodules of chert embedded in the limestone, often at regular distances, like the flints in chalk. A very striking section of this kind is seen in Vallais Bottom, near Frome and Wells. This chert is usually of a dark grey or black colour, but is occasionally white; and in general its colour corresponds to that of the limestone beds which contain it. It is probable that the rottenstone of Dentdale, Swaledale, Aldstone Moor, Derbyshire, and Mold in Flintshire, may be occasioned by decomposition of the shaly limestone near the surface.

Bitumen in solid masses occurs very frequently in the beds of the scar limestone, and enters the cavities of productæ, orthocerata, &c.; as at Castleton, and near Clitheroe.

Physical Geography.—The surface of the country which is occupied by this rock in England is remarkably characteristic. Having been exposed to many repeated movements and changes, it now occupies considerable altitudes, and is placed in a great variety of positions favourable for the exhibition of the changes wrought by the atmos-

[1] The following are a few of the more important species occurring in the carboniferous limestone:—*Lithostrotion striatum, L. irregulare, Lonsdaleia floriformis, Cyathophyllum regium, Zaphrentis cylindrica, Amplexus coralloides, Productus semireticulatus, P. giganteus, Spirifera pinguis, S. striata, S. glabra, Orthis resupinata, Euomphalus pentangulatus, Goniatites* (many species), *Orthoceratites, Nautili*, &c.

phere, or meteoric denudation. It is principally to the hardness and comparative durability of this rock, conjoined with its stratification and extensive system of *joints*, that we owe the grand ranges of vertical escarpments which appear with castellated-like fortifications on the sides of the dales of Yorkshire and elsewhere in Derbyshire, &c.

Swallow Holes.—Frequently upon broad surfaces of limestone, especially where it alternates with shale, deep vertical pits occur, produced by the action of water (rills or rain). These "swallow holes," as they are justly called, often serve to mark out uninterruptedly, for miles, lines of limestones, whose actual edges or outcrop may be obscured by the sliding of other matter over them, or the junction of two different strata.

Swallow holes sometimes communicate downwards into caverns, which are nowhere so abundant as in the lower or scar limestones. It is to them we must refer the numerous caverns of the Mendip Hills, in Somersetshire, the rocks of Clifton, the Forest of Dean, the celebrated caverns of Staffordshire and Derbyshire, and those beneath Ingleborough and Penyghent in Yorkshire; indeed, most of the caverns and so-called caves were excavated through the agency of water thus conveyed from the surface, charged with carbonic acid; and farther north, along the Pennine chain, where these limestones become thinner, the caverns become less numerous, and in the same proportion the phenomenon of underground streams is rarely observed. This phenomenon is evidently dependent on the thickness as well as on the open joints and absorbent surface of the rock, and examples of the same kind occur in various other thick calcareous strata of England, as the Jurassic and chalk, as well as in the Jura limestone or oolite of Germany and France. It is to the same causes that we must ascribe the extraordinary strength of the springs which issue from the openings in this rock; these, being highly charged with carbonate of lime, soon deposit along their channels abundance of tufa and stalagmitic masses. The herbage upon this limestone is usually short, elastic, nutritious, and of a bright and emerald green, which contrasts strongly with the bluish aspect of the moist surfaces of the shales, and the brown tints of the heathy moorlands of millstone grit.

Yoredale Rocks and Upper Limestone Shale.[1]

The general subdivision of the Yoredale series, as given by Prof. Phillips for Yorkshire, is:—

1. Upper limestone belt, consisting of alternations of limestones (often cherty) with sandstones, shales, and coal seams—80 to 300 feet.
2. Flagstone series, consisting of alternations of flagstones, grits, shales, coal seams, and a few beds of limestones—250 to 400 feet.

In Derbyshire.—The shale and grit, or flagstone series above the scar limestone, is called in Derbyshire, Gloucestershire, Somerstshire,

[1] The Yoredale Rocks, so named by Professor Phillips from their development in Yoredale (or Wensleydale) in Yorkshire, consist of alternations of flagstones, gritstones, shales, coal seams, and limestones.

and South Wales, the upper limestone shale. It is from 400 to 500 feet thick, and consists principally of black or brown shale, forming a very wet soil, and causing land-slips of great extent beneath the summits or capping of the millstone grit. Mam Tor, the "Shivering Mountain," near Castleton, exhibits these characters very decidedly. The shale, to a great extent, is interstratified (and with considerable regularity) with thick rocks of fine-grained micaceous gritstone, of excellent quality for building purposes.

In Yorkshire.—This description of the Derbyshire limestone shale would apply with scarcely a varying sentence to the broad argillaceous strata which cover the thick limestones of Craven. The same abundance of shale, occasional interpolations of sandstone, ironstone, and laminated beds of dark limestone, the same traces of coal and liquid bitumen, the same kind of contortions, may be traced in Craven and in Wharfedale. The Yoredale rocks extend from the coast of Northumberland, round the western borders of Durham to Ingleborough, and thence through South Yorkshire into Derbyshire—the limestone varies in thickness in the typical localities, being far less constant than the arenaceous or flagstone series. The following local thicknesses are given by Professor Phillips:—

	Alston Moor.	Swaledale.	Wensleydale.	Penyghent.
Upper limestone belt .	. 274	250	200	80
Flagstone series . .	. 304	250	400	300

Near Halifax these strata attain a thickness of 600 feet.

CHAPTER XXII.

THE COAL FORMATION (OR COAL-MEASURES) OF ENGLAND.

Les Terrains Houillers, France.

THIS important series consists of alternating strata of sandstone, shale, and coal, with courses of nodular clay ironstone, layers of bivalve shells, and in places argillo-calcareous balls and nodules generally enclosing Goniatites, Pectens, Anthracosia, &c.

These strata do not differ individually in any essential points from the analogous deposits in the millstone grit or Yoredale limestone series beneath; their characteristic features are derived from their combination. It is by the *greater abundance* of the coal seams, and by the *absence* of limestone beds, that the Upper part of the Carboniferous system is to be distinguished from the Lower.

Extent of the British and Continental Coal-Fields.—The extent of the coal-fields of England and Wales may be seen upon Greenough's or Ramsay's geological maps,[1] also the map prepared for the Royal

[1] Published by Stanford, Charing Cross.

Coal Commission; the Scottish areas from Professor Geikie's geological map of Scotland; and those of Ireland from the map prepared by the late Professor Jukes, and the still more extensive Irish map by Sir R. Griffith.

For the coal sources of the Netherlands, the Memoirs of Omalius d'Halloy, and for the German and Transylvanian coal-fields, the works of Friesleben, Hoffmann, Sternberg, von Decken and others, may be consulted. Professor Hull, in his able work upon the coal tracts and fields of Great Britain, has given a complete history of their distribution, and also their relation to the European coal basins.[1]

Geological Position of Coal and the British Coal Measures.

The Coal-measures belong to that division of strata termed Upper Palæozoic, and occur, as a rule, above the Carboniferous Limestone, although they may rest upon any older rocks, such being the case in the South Staffordshire coal-field, where the Coal-measures rest at once upon the Wenlock rocks of the Upper Silurian series, and in Shropshire, where they lie upon the Cambrian. In other words, these were the old terrestrial areas or land surfaces on which grew the particular plants which, after growth and subsequent decomposition, were converted into coal, or were carbonised on the spot where they flourished. The many agencies concerned in the deposition of the strata, and the chemical changes which the vegetation underwent, to its complete or final metamorphism, are matters foreign to our present purpose; but, as a great and wonderful life-period, concerned in producing a product of immense economic value to man, the Carboniferous epoch stands alone. Regarded lithologically as a rock-formation or system, the series is composed of sandstones, shales, fire-clays, ironstones, limestones, and coal, alternating more or less with each other, and in many areas or coal-fields as much as 8000 or 10,000 feet in thickness.

The formation or accumulation of such a series of stratified deposits, and the conversion of vegetable matter into almost pure carbon or coal, implies a vast epoch of time, with many and frequent changes in the relative levels of sea and land, or land and water—some being laid down in deep water, others in shallow—some of fresh-water origin, others marine—these conditions being fully exemplified by the fossil contents of the intervening sandstones or shales over many of our own coal-fields and those of Europe. There is little doubt that the coal-measures and underlying carboniferous limestones were deposited and accumulated amidst an extensive archipelago, of which much of Scandinavia, Scotland, Ireland, Wales, England, France, Belgium, Prussia, and Italy formed parts (Nova Scotia and America constituting probably an extended westerly portion of the same.) An important feature of this archipelago was a continuous tract of land, reaching from the Franco-Belgian and Prussian frontier to Somerset-

[1] "The Coal-fields of Great Britain," 3d edition, 1873. Consult also G. H. Kinahan, M.R.I.A., &c., Geology of Ireland, pp. 63-129.

shire and the South of Ireland—still recognised in the Ardennes to the east, the Mendip Hills to the west, and the intervening land between. All this area exhibits similar physical characters.

We may therefore divide the several greater groups of the Carboniferous Period into four conditions or series:—1. *The upper or true coal-measures*, which were chiefly, if not entirely, terrestrial or land formations. 2. *The millstone grit* (arenaceous or sandstone series), chiefly littoral and shallow-water deposits, with little or no coal. 3. *The carboniferous or mountain limestone*, deposited under purely marine conditions, probably rather deep water, and containing a numerous assemblage of fossils, entirely marine, with extensive masses of reef and other corals distributed through the mass. 4. *The lower or carboniferous shales*, which were laid down in shallow water, and perhaps amidst low and swampy lands and islets. Such conditions are still known in the swamps of tropical countries, where the decaying vegetation—mixed with sedimentary matter, both silicious and calcareous—has all the general appearance and condition of the old coal epoch, except that the peculiar vegetation of that remote period now no longer exists. True coal occurs in beds or seams of every thickness, separated from one another by thicker or thinner strata of shale, sandstone, clay, &c., the whole being known as "coal-measures." These intervening strata may be either of marine or fresh-water origin, depending upon the position of contiguous land with regard to the water, the successive periods of plant-growth and decomposition, and the slow and continued depression of the area over which coal-growth and its associated conditions were going on.

The carboniferous formation of the British islands assumes various characters, yet all of one general type or facies, each great area or tract having its own peculiarities, due to conditions during growth, and subsequent physical and chemical changes. Thus, cannel coal is peculiar to one area, anthracite to another, and bituminous coals to a third; yet, originally, all resulted from the growth and decay of one floral type. So with continental Europe and America; the same conditions were universal, and the coal and coal-measures were produced in one long and continued, and perhaps unbroken period or age over the globe, though not absolutely contemporaneous everywhere.

In England and Scotland, we have a great and almost complete succession of measures, and an almost unlimited supply of coal, probably more than exists in all continental Europe combined. The aggregate area occupied by the vast coal-fields of America amounts to 200,000 square miles, or twenty times the area of all the remaining coal of Britain and Europe, with a store of four billion tons of fuel, calculating for a thickness of only 20 feet of coal. If, therefore, coal as a source of motive power is to remain the dominant element, and all mechanical industry is to be governed by it, America has, indeed, a great future for her people. Coal may not always be this power, though at present we are not certain of any other. At the present moment, however, we are, as a nation and people, largely dependent for our supremacy upon it.

Coal Tracts, or Areas.

In Great Britain and Ireland there are ten districts where extensive coal-yielding rocks come to the surface, and no less than thirty-nine smaller coal areas—17 in England, 16 in Scotland, and 6 in Ireland.

Chief Areas in England.—These ten districts, or chief areas, are:—1, Northumberland and Durham; 2, Whitehaven; 3, Yorkshire, Nottingham, and Derby (Midland); 4, Lancashire; 5, North and South Staffordshire; 6, Flintshire; 7, Shropshire; 8, Forest of Dean; 9, Bristol coal-field; 10, South Wales.[1]

The smallest of these contains an area of 60,000 square acres, and the largest 600,000; the entire known acreage in England equals 2,500,000, and in Scotland 1,000,000 square acres; or about 6000 square miles of coal-measure land occurs in Britain, a total of 4,050,000 acres.

Scotland.—In Scotland there are five areas of considerable magnitude, divisible into sixteen coal-fields. The five areas are:—1, the Lothian; 2, Fifeshire; 3, Clackmannan and the Clyde basin; 4, Ayrshire; and 5, Lesmahagow.

Ireland.—Ireland possesses only six tracts or fields:—1, Antrim; 2, Dungannon; 3, Tipperary; 4, Kilkenny; 5, Tyrone; 6, Clare, Limerick, and Cork.

Physical Geography, &c.—These coal-fields are separated at the surface by the overlying New Red Sandstone, and sometimes, as in the Bristol coal-field, by the succeeding Lias and Oolite. They are, however, connected underneath, and therefore were so originally at the surface, or at the time of deposition or growth. The divisions into the now so-called "fields" are, however, frequently due to physical causes, such as great flexures of the strata, faults, and denudation subsequent to and since these movements. As examples, we may mention the great coal-fields of South Wales, the Forest of Dean, and the Bristol coal-fields, which unquestionably were originally one, since separated by great flexures and folds, and modified by the denudation and removal of nearly all the superincumbent strata once overlying the whole. The strata comprising the Welsh coal-field are nearly 10,000 feet thick, and those of the Bristol coal-field 6000 feet; much of the coal in the latter field will never be reached or realised, owing to its depth and the physical structure of the basin.

The South Staffordshire and Worcestershire coal-fields are nearly related, if they are not, indeed, one and the same, at considerable depths; and the Durham, Newcastle, Yorkshire, Lancashire, Derbyshire, Nottinghamshire, Leicestershire, and Warwickshire fields have many features in common, and, if laid bare (*i.e.*, if all the superincumbent strata were removed down to the old land surface) they would probably appear as one great terrestrial tract—the original surface,

[1] The largest and most important are the five following:—1, Newcastle and Durham; 2, Lancashire; 3, Yorkshire, Nottingham, and Derby; 4, South Staffordshire; 5, South Wales.

over which the coal-flora flourished, decomposed, became carbonised and fossilised.

The more northerly or Scottish coal-fields have peculiarities of their own, both as regards the coals and their earlier development or growth, as well as the rocks which contain them; for by far the greatest part of the workable coals or coal series of the Scottish fields is included in the limestone group (either the carboniferous limestone series or the calciferous sandstone, &c., below). The important fields of Lanarkshire and Ayrshire, with their fine gas or parrot coals, splint, and black bands or beds of argilo-calcareous iron, all occur in a group of rocks in which coal was accumulated prior to the time at which many of the English deposits commenced.

Ireland, although now poor in coal, is nevertheless one-half covered by *rocks of the carboniferous system*, such as the carboniferous limestone, Yoredale beds, and lower coal-measures; yet, comparatively speaking, Ireland scarcely possesses or produces coal in any quantity. The coal-measures of the south of Ireland resemble the western extremity of South Wales, and those of the north of Ireland the north of England and Scotch deposits. Doubtless they were once one continuous terrestrial surface. This may also be said relative to our original connection with the European continent, especially that portion belonging to the Belgian, Westphalian, and French areas—notably to the two former—and over the region now occupied by the German Ocean and part of the English Channel. The Belgian coal-field extends into and constitutes a part of France as far as Valenciennes, occupying a "long and narrow trough from Aix-la-Chapelle to Liége, Namur, Mons, Valenciennes, and Arras; and we believe, upon physical grounds or evidence, that the coal-measures trend westwards beneath the cretaceous rocks to within 30 miles of Calais."

Land Depressions and the Coal-Measures.—The physical facts connected with coal and the coal-measures, and their original deposition and formation, are of the highest interest, and offer some of the most difficult problems to the geologist for solution and elucidation. When we realise the fact that much of our coal lies buried 6000 or 8000 feet below the sea, and that one European coal-field—that of Saarbrücken—occurs over 21,000 feet below this (or equal to the height of Chimborazo above it), it opens up a question of the highest cosmical interest. We have still in the valley of the Jordan an extensive area nearly 3000 feet below the level of the Mediterranean and Red Sea—in other words, the surface level of the Dead Sea is 1340 feet below the surface level of the two seas named, and the depth to the bottom of the Dead Sea is about 1370 feet more, thus making the land depression of that area 2710 feet. In connection with such known modern instances, we may notice, amongst others, the following greater cases of depression, all of which either occurred since, or were gradually taking place at the time of the growth of the coal-forests, and their conversion or metamorphism into what is now coal. The five localities named will suffice to show the extent of these great depressions, once coal-plant-growing surfaces:—

1. The Mons coal basin in Belgium, which is 5330 feet below the level of the sea. 2. That of Liége, nearly 4000 feet. 3. Saarbrück coal-field, in the Rhenish provinces of Prussia, with an area of nearly 900 square miles, now depressed 21,000 feet below the level of the sea, in the district of Duttweiler near Bettingen. The fact that the fossil remains of these measures are terrestrial, marine, and fresh water, shows repeated oscillation of level during the accumulation. This depth below the sea is equal to the height of Chimborazo and the Himalayas above it; and according to calculation, the temperature at such depth may be as high as 467° Fahr. 4. The Bristol coal basin, the southern part of which lies in a depression from 6000 and 8000 feet below the surrounding sea level, the outcrop edges of the lower series only being at present worked. The deeper part of the basin will probably never be touched. 5. The great South Wales coal basin, the deepest portion of which is about 6000 feet below the level of the Bristol Channel. "We have, therefore, from the highest summits of the Andes or Himalayas, to the lowest parts of known coal basins, or fields containing coal in Europe and Britain, a vertical distance of 48,000 feet or $\frac{1}{4\,3\,5}$ of the earth's semi-diameter."

British Coal-Fields.[1]

In Great Britain and Ireland, we have 21 principal coal tracts, or chief districts, where the coal-measures are exposed at the surface, occupying an area of 3000 to 3500 square miles. The 38 coal-fields comprised within these tracts—viz., 16 in England, 16 in Scotland, and 6 in Ireland—being minor divisions, have in many instances physical demarcations or boundaries, although they doubtless once formed one great and more or less continuous continental land surface, when Britain was united to, or formed an integral portion of, the continent of Europe.

1. *The Great Northern or Northumberland and Durham Coal-Field.*

The coal-field of Northumberland and Durham lies north of the Yorkshire coal-field, and on the east side of the Pennine chain. This great area, from its importance as a coal-field, the nature of its coals, and its geological features, cannot be passed over without special mention. It occupies an extensive area, about 50 miles in

[1] The British coal-fields may be classed under 3 heads—1. Those forming complete basins, *entirely circumscribed or surrounded* by the lower members of the Carboniferous series, such as the *Forest of Dean and South Wales* basins. 2. Those in which one limb of the basin only is visible, the opposite one being obscured by Permian or other strata of newer date. Of this class, the *Northumberland and Durham coal basin* is an example. 3. Those in which the boundaries are formed by faults, and which bring down the upper or overlying strata in contact with the coal-measures. This group is illustrated by the *South Staffordshire field.* The two last classes are of the greatest geological interest, from the fact of their probable extension within workable limits beneath the overlying strata.

length and 20 miles in breadth, ranging from the north bank of the Tees on the south, to near Warkworth and the river Coquet on the north. The German Ocean constitutes its eastern border or boundary. The structure of this field is that of an irregular basin or trough, whose longest axis coincides with its longitude; much of its mass and eastern limit is beneath the North Sea, the beds rising to the east and dipping to the west.

The southern part of the coal-field is depressed to the extent of 700 feet; this is due to the fault known as the "*Butter Knowle Dyke*," which ranges from the E.N.E. to the W.S.W. It is doubtful if the coal-measures occur south of the Tees—trials for coal by boring to the depth of 1800 feet having reached only the Triassic rocks in which rock salt occurred, the Permian not being touched. The carboniferous limestone of the Pennine chain determines the western limit of the coal-field, the scar limestone there rising to the height of 2350 feet.

The magnesian limestone which covers the eastern half of the Durham coal-field is about 700 feet thick; the Coal-measures comprising the Upper, Middle, and Lower series, about 3000 feet; the Millstone grit 400 feet; the Yoredale beds 550 feet; and the Scar limestone 1120 feet.

The rivers Blythe, Tyne, and Wear naturally give names to the three divisions or "Fields"—viz., the Field of the Blythe, or Blythe coal-field, the Tyne coal-field, and the Wear coal-field. But these are all really one, and all embraced between the river Coquet, near Alnmouth, on the north, to near Staindrop on the north bank of the Tees, on the south—an area, as above stated, of about 50 miles in length by 20 in breadth.

This area may again be trebly described—the Blythe area as a *visible coal-field*, the Tyne area as a *concealed coal-field*, and the Wear area as a *submarine coal-field*, which ranges under the German Ocean, but the coal-beds of which are believed to be available. The seaward extension has been proved in several deep pits in the neighbourhood of Sunderland, especially at Rhyhope and Monkwearmouth, where coal is worked at a depth of 1850 feet. The coals there are flat, but rise to the eastward, proving that the centre of the basin has been passed.

The Blythe coal area contains 460 square miles; the Tyne coal area, 225 square miles; the Wear, under the German Ocean, 111 square miles—in all, 796 square miles.

At Monkwearmouth Colliery the coal-seams lie 2270 feet deep. The nature of the coast sections, north of the Tyne, and the easterly rise of the coal-measures, confirm the belief in the trough-like structure of the coal-basin, whose longer axis is north and south, thus tending to show the probability of a productive coal area extending eastwards under the German Ocean.

The total thickness of the coal-measures, from the lowest seams upwards, is little more than 2000 feet. The available thickness of coal is about 45 feet, spread over an area of 800 square miles. The

chief seams are the High Main (6 feet thick), the Bensham (6 feet thick), the Low Main (6 feet thick). Twelve other seams occur, yielding 30 feet of coal in the vertical section, or thickness of the field.

Numerous basaltic dykes traverse the coal-field in straight lines from east to west, where, in contact with the coal, the bituminous variety is converted into anthracite. These dykes cut across the faults, thus determining their age to be posterior; the date of their intrusion may be Miocene, or the same as the dolorites and basalts of the west of Scotland and north of Ireland. The great 90-fathom dyke constitutes one of the largest faults in the coal-field, and much disturbs the strata along its course, depressing the country north of and between Cilingworth and Gosforth to the extent of 200 fathoms. The age of many faults that traverse the coal-field from west to east is *pre-Permian*, since they do not affect the magnesian limestone.

The Northumberland division possesses an available quantity of terrestrial (exposed) coal equal to 2560 millions of tons, while the quantity under the sea (concealed coal-fields) may be estimated at 400 millions of tons. The land coals of Durham will probably realise 3600 millions of tons, and those beneath the ocean (with a seaward breadth of $3\frac{1}{2}$ miles, and an area of 71 miles) 735 millions nearly, the total being 7295 million tons.

2. *Leicestershire Coal-Field.*[1]

The Leicestershire or Ashby-de-la-Zouche coal-field is an irregularly-shaped area, about 30 miles square, on the west side of Charnwood Forest. The coal-measures underlie the New Red Sandstone to an unknown distance south and south-west. The coal-field is physically divided into three districts—Moira on the West, Ashby De-la-Zouche in the centre, and Coleorton on the East. The central district contains coal-measures, but no workable coal. The main coal-seam of "Moira" is from 12 to 14 feet thick, that of Coleorton from 6 to 8. There are *seven chief seams* in this basin, all in the middle series, the *lower* being unproductive. Probably the coal-measures here rest upon the carboniferous limestone, except perhaps those of the eastern end, which may lie upon the Cambrian strata of Charnwood Forest. At Whitwick a sheet of dolorite or melaphyre (whinstone) intervenes between the coal-measures and the New Red Sandstone. Evidently, this was a sheet of lava poured out over the denuded surface of the coal-measures prior to the deposition of the Trias, probably from a volcanic vent situated at the junction of the coal-measures with the old rocks of Charnwood. The following is the general succession of the strata:—

[1] See Hull, "Coal-fields of Great Britain," pp. 224-230.

Sequence of Strata in the Leicestershire Coal-Field.

Trias.	Keuper series	700 feet.
	Bunter (sometimes absent)	200 „
Permian.	Breccia sparingly represented.	
Carboniferous Series.	1. Middle coal-measures with about 20 seams of coal, of which ten are workable	1500 „
	2. Lower coal-measures, unproductive	1000 „
	3. Millstone grit	50 „
	4. Yoredale series and carboniferous limestone.	

3. *Lancashire Coal-Field.*

The Lancashire coal-field is one of the most important in Britain. It is 32 miles long by 6 wide, and has an area of 217 square miles, 6000 feet of coal-measures, 65 seams of coal, with the united thickness of 100 feet, and a reserve of fuel for future supply, according to Mr. Dickinson, of 3346 million tons. It is impossible to attempt here any analysis of the complicated structure of this coal-field.[1] The overlying Trias (Keuper 3500 feet, and Bunter 1250 feet = 4750 feet) is nearly 5000 feet, and the Permian 750 feet thick. These beds surround and partly cover up the western and southern parts of the field; did they cover it entirely, no coal could have been won; and so completely has denudation levelled the displacements caused by the numerous and great faults which traverse the area, that their effects are scarcely perceptible at the surface. One of the largest, the "Great Up Holland fault," between Rainford and Wigan, disturbs the county vertically 1950 feet. Again, the Great Pendleton or Irwell Valley fault (along the valley of the Irwell) has a downthrow of 3000 feet; and in the Wigan area "the coal-measures are divided into areas bounded by parallel faults which range N.N.W. with every variation of amount."[2] The chief coals are the "Arley Main" (at the bottom of the middle series), Rushey Park, and the well-known and valuable "Wigan cannel."

In the Burnley district, the lower and middle coal-measures together are from 2500 to 3000 feet thick; the upper measures are wanting. The cannel coal has yielded remains of Megalichthys and Ctenoptychius; and the genus Anthrocosia, an estuarine bivalve shell, resembling Unio, characterises several strata.

In the Clitheroe and Pendle district, the Yoredale rocks assume extraordinary thickness (3500–4000 feet). It seems almost incredible that such a mass of strata should not be represented in Scotland.

The explanation of the Scottish series may be found either on stratigraphical or palæontological grounds in the representative stages given below. Placed side by side, we have the following comparisons:—

[1] Vols. i. and ii. of the Trans. Geol. Soc. of Manchester contain able papers on this coal-field by Mr. Binney, F.R.S. Consult also the Mem. Geol. Survey, "Geol. of Oldham and Manchester," 1862; *ibid.*, "Oldham," 1864; Hull, *op. cit.*; and the Geol. Survey Maps of Lancashire, which are on a scale of 6 inches to the mile.

[2] Hull, *loc. cit.*, p. 196.

Representative Stages.[1]

	North of England.	Central Scotland.
Stage E.	Gannister beds.	(E.) Slaty blackband series.
„ D.	Millstone grit.	(D.) Moorstone-rock series.
„ C.	"Great limestone." Flagstones and shales.	(C.) Upper limestone series. Lower coal and ironstone series.
„ B.	Scaur-limestone series.	(B.) Lower limestone series.
„ A.	Sometimes absent (Tuedian).	(A.) Calciferous sandstone series.

This view is corroborated by Mr. Lebour, who states that, on comparing a list of 130 species from the Great Limestone of Northumberland (the most marked Yoredale bed) with Scotch lists, he finds that 32 species are not known in Scotland, about 60 occur through the three Scottish divisions, 28 occur only in the Scotch upper and middle series, and 10 species only are found in the lower series. Allowing for the difference in geographical position, and recollecting that probably during the earlier Carboniferous periods the Scotch and English marine areas were to some extent separated by the barrier of old land (Silurian or Cambrian), this community of 28 species corroborates the views suggested:—"We must remember that, over the north of England and the borders of Scotland, land and shallow-sea conditions prevailed during the deposition of the earlier Carboniferous stages. This fully accounts for those changes in the thickness and condition of the limestone series, since such changes would necessarily be accompanied by the disappearance of forms which flourished in the deeper seas of central England, and the appearance of others better adapted to shallow-water conditions."

4. *Coalbrook Dale Coal-Field.*

On the east side of the Silurian ranges of the Wrekin and Wenlock Edge, lies the coal-field of Coalbrook Dale.

We are indebted to Professor Prestwich[2] for a complete survey of this remarkable coal-field, which on the north and east is entirely bounded by faults, and New Red and Permian rocks. On the west it rests on a representative of the Millstone Grit, or on Carboniferous Limestone, or on some of the several beds of the Silurian series. On these Silurian rocks it is unconformable, and for the most part this unconformity is proved on a large scale; but, as in the Dudley field, to which this bears more than analogy, there is in many places very little difference of direction or angle of dip between the Silurian and Carboniferous strata. The coal-field is bounded on the west by Caradoc sandstone and its associated igneous rocks, and on the south-east by the Old Red Sandstone and Upper Ludlow. Between these extremes the Lower Ludlow and Wenlock series may be seen, the coal not so much abutting against as resting on them.

[1] The stages B and C in Northumberland Mr. Lebour has included under the name "Bernician beds." See Note, *ante*.

[2] Trans. of the Geol. Soc, vol. v. p. 18.

Perhaps there is no coal tract known which, in so small a compass (about twelve miles long, and, at most, three and a half miles wide) exhibits so many curvatures in the outcrops, and is crossed by so many continuous faults, some ranging N. by E., others E.N.E.; these, again, are also crossed by many of shorter length, and directed W.N.W., and in several other lines.

The total thickness is supposed to be 1000 or 1100 feet, divided into 90 distinct strata. The coal varies in thickness from 16 feet to 55, and in the number of its beds from 7 to 22, the increase being to the north. The "cleat," or system of joints, runs from west-north-west to east-south-east. The coal is, for the most part, of the variety called "slate" coal in Scotland, and "hard" coal in Derbyshire. Petroleum abounds in the central and upper part of the field. The coal-seams are mostly thin; the ten uppermost are too sulphurous or pyritic for other uses than lime-burning, and are called "stinkers;" twelve beds of good coal, in all 25 feet thick, the thickest being 5 feet, succeed, and the lowest bed of the whole formation, 8 inches thick, is sulphurous. Ironstones abound, and, like the coal-seams, increase in number and thickness towards the north, from 1 to 8 bands, and comprise a thickness (including the shales worked with them) of 3 feet to 72 feet.

The distribution of the organic remains in this coal-field has been fully investigated by Mr. Prestwich.[1] Five decided alternations of marine and fresh-water life, and two doubtful ones, are placed on record by this author in his important memoir. The most remarkable of these marine bands is the Pennystone ironstone in the lower part of the section (perhaps comparable to the new mine, also a marine layer, in the Dudley field), and next to it the Chance Pennystone, which is in the upper part. The marine remains are numerous.

5. *South Staffordshire Coal-Field.*

This is one of the most important coal-fields of central England, differing from all others in the character of the subjacent or underlying limestone, which is Upper Silurian (Wenlock limestone and shales), no Millstone Grit or Carboniferous Limestone, on which the coal usually rests in other fields, being present. In other words, the old land surface on which the coal flora grew was an eroded surface of Upper Silurian rocks. The late Professor Jukes, in his able memoir upon the "South Staffordshire Coal-Field,"[2] has clearly shown that, whilst the same accumulations were going on in other parts of England, a broad tract of country, spreading from what is now Shropshire, across Staffordshire and Warwickshire, was dry land. Consequently, the usually associated or normal conditions of other coal-fields are here wanting; "both the grits and limestones of the Carboniferous series being absent, the well-marked isolated Silurian masses of Dudley, Sedgley, and Walsall rising from beneath the coal-measures on which they rest." This coal-field embraces the district of Cannock

[1] Trans. Geol. Soc., vol. v. p. 413-495. [2] Mem. Geol. Survey.

Chase, Bilston, and Dudley, a range of country 20 miles north and south from the Clent Hills to Rugeley, with a breadth of about 10 miles. The Bunter sandstone and Pennian rocks which surround the coal-field are very thick, the former being 1200 feet, and the latter about 2000 feet. The coal-measures, divisible into upper and middle, are nearly 2000 feet thick; all the coals occur in the latter series, the upper group being barren.

The middle group contains six seams of coal, having the united thickness of 65 feet, one of which is the celebrated main, thick coal, 10-yard or 30-feet seam, the thickest known seam in England. This great accumulation, composed of eight or ten distinct beds, closely superposed one upon the other, splits up into nine distinct seams at the northern part of the coal basin near Essington and Pelsall. These nine seams, though divided and separated by 420 feet of sandstones and shales (combined), yet still equal in thickness the 30-feet seam,—in other words, the latter is one seam of coal, measuring 30 feet thick, at and near Dudley, but to the north divided into nine "separated representatives," each having its own land surface, underclays, roof, and fossil contents. The presence of this great bituminous mass in the southern part of the coal-field is "*a feature of importance without a parallel;*" it is being rapidly exhausted, and ere long will only "*be matter of history.*" Among the peculiarities of this coal-field are the contemporaneous and eruptive igneous rocks, and the prevalence of intrusive dykes and great lava-flows during the accumulation of the coal-measures, as exemplified by the basalt of Rowley Regis, or Rowley Rag, which assumes the prismatic and columnar structure. The coal underlies this great contemporaneous lava-flow, which "*forms a hill two miles in length, and 820 feet in height,*" and which has charred and burnt the coal in places so as to render it worthless. Other chief features associated with the coal are beds of argillaceous iron ore, of which no less than eight occur, interstratified with the *brooch, heather, thick new mine,* and *bottom coals.* The resources of this coal-field, as stated above, have been greatly drawn upon. The quantity of coal now remaining in the northern and southern portions of the coal-field may nearly equal 950 millions of tons. In 1870, 9,346,000 tons were raised from 326 collieries; and in 1878, 9,130,800 tons from 395 collieries. At this rate of consumption, in 103 years this coal-field will be exhausted. No less than 850,000 tons of iron ore were raised in 1870, averaging 33 per cent. of pig iron. In the same year 114 furnaces were in blast, turning out 580,000 tons of pig iron. At the present rate of consumption the 10-yard or thick coal near Dudley will only last 40 years. Most of the organic remains are marine, and they occur abundantly in the shales and ironstones of the "pennystone."

6. *North Staffordshire Coal-Field, or Pottery Coal-Field.*

On the west side of the Pennine axis, and between the same parallels as the Derbyshire and Yorkshire coal-fields, are those of

North Staffordshire and Lancashire, with an exposed area of about 94 miles. This triangularly-shaped coal basin, between Congleton and Newcastle-under-Lyne, is of high importance economically, containing 38 seams of coal, its resources being far greater than those of the South Staffordshire area; twice the thickness of workable coal occurs, and many of the seams are roofed by beds of valuable argillaceous iron ores. The coal-measures are divided into upper, middle, and lower. The upper is barren of profitable coal. The middle, or pottery coal and ironstone-measures, about 5000 feet thick, contain about 40 seams of coal, associated with ores of iron. The lower group comprises black shales and flags, with the furnace coals, 17 or 18 seams in number, over 2 feet in thickness. The total thickness of coal in one area is 140 feet. In another, where 24 seams occur, it is 109 feet, interstratified with courses of carbonaceous ironstone or black band from 2 to 6 feet thick, crowded with the characteristic shells, Anthracosia and Anthracomya. From the northern part of this rich field at Rugged Mow-cop Hill, near Congleton, sixteen areas, more or less separated, can be distinguished. The detached works about Cheadle belong to the Gannister or Millstone Grit series, and are continuous with those of Macclesfield, Whaley Bridge, and Glossop. Geologically, they had a common origin, being portions of one vast deposit, which in time has been modified by depression, elevation, and denudation—depressed and covered by newer strata, at one period of its history, then upraised and denuded synchronously at another—so that "whilst the higher portions may have stood 8000 feet above the crests of the Peak of Derbyshire, the lower beds may dip down from the Buxton moorlands to the depth of 12,000 feet beneath the plains of Cheshire."[1]

The resources of this richly stored coal-field are very great. It contains 30 seams of the united thickness of 150 feet, and an available quantity of coal amounting to 3700 millions of tons. In 1878, 145 collieries produced over 4 millions of tons of fuel, 1,720,500 tons of which were consumed and used in the production and manufacture of iron. In the same year, 24 blast furnaces produced 303,378 tons of pig iron from 910,134 tons of ore. At the present rate or yield, the coal of this remarkable field will last nearly 1000 years.[2]

Many of the beds throughout the field abound in organic remains, no less than 50 species of fish having been recognised. The mollusca, like the fish, are of marine origin, thus clearly showing, with the associated plants of the coal, that the whole was accumulated under estuarine conditions.

7. *Clee Hills Coal-Field.*

The divided coal-basin of the Clee Hills is placed upon the Silurian and Old Red Sandstone, which slopes eastward from Corvedale. Several seams of coal and layers of ironstone occur, much confused in

[1] "Coal and Coal Mining," by Professor W. W. Smyth, F.R.S., p. 54.
[2] Mineral Statistics in Professor Hull's "Coal-Fields," p. 170.

their arrangement by the interposition of basaltic dykes and overlying masses, and resting below on a hard conglomerate sandstone. This interesting country was minutely examined by Murchison. On three sides of the Brown Clee Hill the coal strata rest on Old Red Sandstone, which to the west is a coarse conglomerate; but on the fourth or south-eastern side there is interposed between the Old Red and the lower coal grits a thin zone of Carboniferous Limestone.

Trap rocks confuse the arrangement of the coal strata in the whole space between Corvedale and the Severn, including the coal-field of Billingsley and Bewdley. The beds of coal are thickest in the Clee Hill collieries; at Knowlsbury the great coal-seam is 7 feet thick.

8. *North Wales Coal-Fields.—Denbighshire and Flintshire.*

We notice these unitedly on account of the nature and value of their mineral contents, the coals in which are important as gas and oil producers to a large extent. The seams of coal in the Denbighshire field are not numerous—nine in number; two of them (the upper sulphurous) are not worked. The coals of the middle series are the most valuable, the seven seams unitedly realising 30 feet of coal. The Ruabon coals are worked at Hafod to the depth of 1500 feet. The Flintshire and Denbighshire coal-fields were undoubtedly deposited in one area and as one land surface, now divided by the Millstone Grit, and severed by the great Bala fault.[1] This dislocation it is that geographically and geologically separates the two areas into two workable coal-fields, and is the cause of their present disunion or severance. The Denbighshire coal-field is 18 miles long by 4 in width, and rich in argillaceous iron ores, the "brassy and black band" beds yielding vast quantities of ore. The amount of coal raised by 23 collieries is over 1,500,000 tons. The store known is 1287 millions of tons down to 4000 feet. It has been calculated that exhaustion at this output will last us 800 years. Mr. Hull, however, does not estimate the store at more than 700 millions. These differences in computation arise from estimating many thin seams which may never be utilised.

The Flintshire coal-field extends for 15 miles along the western side of the estuary of the Dee to the Point of Air. It is greatly faulted along the coast; the coa-lseams dip beneath the estuary, reappearing through a fault near Parkgate, and underlie the New Red Sandstone of the Wirral promontory and the Cheshire plain. There is no doubt whatever about the correlation between the coals of the Denbighshire and Flintshire fields; the seams are the same under different names. So with the "intermediate" ironstone-measures; they also correspond with those of Denbighshire. Cannel coals of compact structure and of high gas-producing quality constitute a portion of the "Hollin coal," and the "lower four-foot," or Leeswood, near Mold. This four-foot coal is reputed to yield a larger percentage of gas than the far-

[1] One of the most extensive faults in Great Britain, traceable from the sea, in Montgomeryshire, to Cheshire, with a displacement of 10,000 or 12,000 feet.

famed Wigan cannel, but the rich gas-producing area is comparatively small.

The unwrought and available coal is estimated at 718 millions of tons. This includes the tract along the estuary of the Dee and the Neston field. The future of this coal-field depends upon the north-easterly extension of the coal-measures into Cheshire, &c. Doubtless great deposits occur, and there is no reason why they should not join the South Lancashire coal-field.

9. *South Wales Coal-Field.*

Next to the Clyde area, this is the largest coal-field in Great Britain, occupying as it does the greater part of the four counties of Monmouth, Glamorgan, Carmarthen, and Pembroke, and ranging from Pontypool on the east to St. Bride's Bay on the west. This great coal tract occupies about 900 square miles, and the coal-measures have a vertical thickness of nearly 10,000 feet.[1] The Old Red Sandstone beneath is from 8000 to 10,000 feet thick on the north side of the coal-field, and constitutes the highest ground in South Wales, rising to the height of 2900 feet above the sea level, along the northern side or outcrop of the coal-basin; the Vans of Brecon and Carmarthen reach the height above mentioned. At the time of the deposition of the coal-measures of this extensive area (South Wales, Devon, Gloucester, and Somerset), the land was periodically depressed—intermittently, yet continuously. The number of coal-seams, great or small, affords indices of pauses or epochs of stability, clear evidences of a land surface having little elevation above the sea, on which the flora of the coal tract accumulated. Depression must have gone on during the whole of the carboniferous epoch, until nearly 10,000 feet of strata (sandstones and shales) were spread over what is now the great western coal tract, embracing the coal-fields of South Wales, Dean Forest, the Bristol or Gloucester and Somerset field, North Devon, the South of Ireland, and an area now lost under the St. George's Channel. This great region was gradually depressed 10,000 feet during the deposition of the coal-measures, and has since been slowly elevated again, denudation having removed much of the originally accumulated coal-measures and older rocks surrounding the basin. Inconceivable, indeed, is the period required for the depression and re-elevation through a movement of 20,000 feet over this extended area, with time also for the growth and development of the coal flora and its conversion into coal. Carmarthen Bay divides the coal-field into two portions, that to the east, as far as Pontypool, being about 56 miles, and that to St. Bride's Bay, to the west, 17 miles in extent. The greatest transverse

[1] This great thickness is only surpassed in depth by that of Nova Scotia and Saarbrück in Rhenish Prussia. Sir W. Logan and Sir H. de la Beche give nearly 12,000 feet of coal-measures, from the top of the carboniferous limestone to the highest of the Llanelly series; i.e., coal-measures, 10,000 to 12,000 feet; millstone grit, 300 to 400 feet; carboniferous limestone, 1000 to 1500 feet; lower shales and limestone, 400 to 500 feet.

diameter is 16 miles, about the meridian of Neath. Swansea Bay also deeply indents the southern portion of the coal-field, and doubtless, with Carmarthen Bay, covers up or overlies a vast mass of coal-measures. A well-marked anticlinal axis traverses the coal-field east of Carmarthen Bay; thus, along this line the coals occupying the centre of the field are brought much nearer to the surface, and especially so from Risca by Pontypridd, and on to Swansea Bay. The coals thus lie in a north and south trough, or two parallel basins, the northern portion occupying nearly double the area of the south. It is questionable if any of the minerals occupying the centre of the basin could ever have been worked but for this longitudinal elevation, which brings within reach the lower coals that would otherwise have been reached only along the north and south outcrops. South of the axis the coal-measures are 11,000 feet thick, and 7000 feet on the north side in the western district. In the central portion, near Britton Ferry, they diminish to 4800 feet on the north side. The coal-bearing portions are divisible into three groups—

1. Upper Pennant series.
2. Lower „ „
3. White ash series.

The character of the coals undergoes a remarkable change, chemically and physically, from east to west. The series occupying the north-east side of the basin are mainly coking or partially bituminous; those to the west and north-west are anthracitic; while those on the south side are bituminous or gaseous. The coals in the centre of the basin are semi-bituminous or steam coals. In the Aberdare area the coals are very free-burning, but, at the same time, smokeless; hence their importance for steam purposes, especially the Aberdare 4-feet steam coal.

The coal-measures are divided into *Upper* or Penllergare series, more than 3400 feet; the *Pennant grit* series (Swansea), 3246 feet; and the lower coal-measures, 450 to 850 feet; or the

Llanelly series, with several beds of coal	1000 feet.	
Penllergare series of shales, sandstones, and beds of coal—110 beds, 26 beds of coal	3000	„
Central series (Townhill sandstones of Swansea—Pennant grit of the Bristol field)—62 beds, and 16 beds of coal . . .	3246	„
Lower shales, coals, and ironstones (Merthyr)—266 beds; 34 beds of coal	812	„
Abundance of ironstone and unionidæ occur.		
Farewell rock and Gower shales, above the carboniferous limestone.		

Twenty-five seams of coal are known which exceed 2 feet in thickness, and reach a total of nearly 100 feet of coal. "The depth to the lowest *important seam*, called the black vein, is 650 yards, or 2100 feet; and the lowest workable coal is reached at 2250 feet in the valleys" (Smythe).

The chief, and almost the uppermost notable coal-seam in Monmouthshire, is the Myndd-Isslwyn, 5 feet 6 inches thick. This seam

determines the position of the "Pennant," an important arenaceous and micaceous sandstone rock of great thickness (2700 feet) and economic value, both in the Welsh, Forest of Dean, and Bristol coal-fields. The Upper Pennant series contains all the free-burning and bituminous coals, and also the house coals of Monmouthshire, about 100 feet of coal. The Lower Pennant series contains the steam coals, and in places the blackband ironstone, also coking coal in the Rhondda Valley. The lowest or White ash series contains the bulk of the steam and iron-making coals; they are 500 feet thick on the east side, and 1000 feet in the centre of the basin. The total area of the coal-field is about 1000 square miles, of which 153 square miles lie beneath the sea in Swansea and Carmarthen Bays. According to the quality of the coal produced, the area is divided as follows:—

Bituminous coal district	410 square miles.
Anthracite	410 „ „
Intermediate or semi-anthracite . . .	180 „ „

This last, the semi-anthracite or smokeless steam coal, is the most valuable in the field, and is shipped to every port of the world for steam navigation.

The coal-measures of this great basin, with its associated shales—ironstones, sandstones, and the 25 coal-seams of more than 2 feet thick—measure, according to Professor Hull, 11,650 feet. The same author has determined the resources of the field. It is estimated that the total quantity of coal[1] available down to 4000 feet[2] is 32,456 millions of tons; 673 million tons are eliminated from this amount, for what we believe to be over-estimation for thin seams. The quantity of available coal under 4000 feet, after proper deductions, is estimated also at nearly 32,000 millions of tons; but this may never be realised. In the year 1880 the production from this coal-field alone was 17,420,112 tons; we may, therefore assume that coal enough exists within the field to last us 2000 years.

Anthracite Coal.—The area occupied by anthracite coal overlies igneous rocks, both eruptive and contemporaneous, which, through high internal temperatures, *may* have caused those changes in the nature of the coal during or after carbonisation, which resulted in its conversion into the variety known as "anthracite" coal. Or, again, an equally high temperature may have been induced by extreme pressure due to the vast mass of once overlying strata, for some of the lower seams must have been covered to the depth of 10,000 or 12,000 feet (*since removed by denudation*). The temperature, therefore, must have exceeded that of boiling water, thus slowly liberating the gases, and converting the bituminous matter into pure carbon (or nearly so) in the form of "anthracitic" or stone coal, the result being due to heat produced by pressure, added to internal heat. Certain it is, that only the lowest seams of coal, and those existing over a definite area,

[1] After deducting for waste, working faults, bad coal, &c.
[2] The limit allowed for future working.

are thus highly carbonised, or converted into non-bituminous or anthracite coal.

It is clear that these anthracitiferous coals were not an original variety, but a modification of the same beds which remain bituminous in other parts of the area or region in which they occur. In other words, anthracite coal was not a separate deposit in another estuary or land surface. Neither is it an interpolation among other bituminous coals, but—the bituminous beds altered into a natural coke, from which the volatile bituminous matter (oils, gases, &c.) have been driven off by heat, however produced.

The geographical distribution of these non-bituminous smokeless coals is worthy of attention, and has not been sufficiently studied. They are extremely local, yet widely separated. We doubt not that the physical and chemical conditions producing them were much the same everywhere. They occur extensively in the west and north-west part of South Wales; sparingly at Walsall, and at Kilkenny, in Ireland; at Bideford, North Devon, they are impure, in the form of culm, and nearly valueless. America may be said to be the great storehouse for anthracite coal; there it is truly inexhaustible, and is applied to all the demands of art, science, and domestic use. Pennsylvania, Massachusetts, &c., abound in this variety of fuel.[1] In 1820 only about 500 tons of this coal were used; now, 20 million tons are consumed.[2]

10. *Gloucester and Somerset, or Bristol Coal-Field.*

This coal-field, one of the most interesting and important of the western coal areas, was once a portion of, or united to, the great South Wales and Forest of Dean basins, subsequently separated by extensive vertical movements or folds of the surrounding strata of Carboniferous limestone, Old Red Sandstone, and Upper Silurian, which have since been planed away and removed by denudation, thus exposing the three fields as isolated areas, otherwise closely allied physically. The extreme length of the Bristol or Gloucester and Somerset basin, from its northern apex at Cromhall to the northern flanks of the Mendip Hills, is about 25 miles, separated in the middle, near Kingswood, into two basins by an extensive roll, thrust, or anticlinal axis, by which the lower coals of the centre of the basin on both sides of this axis are brought sufficiently near the surface to be extensively worked. Otherwise they could never have been reached and utilised.

Nearly one-fourth of the northern or Coal-pit Heath and Parkfield area is overlaid by the nearly horizontal strata of New Red Sandstone and Lias, and nearly nine-tenths of the southern portion of the coal-field, from Bristol to the Mendips, is covered in the same manner by 380 feet of Triassic and Jurassic rocks, many of the shafts pene-

[1] The coal areas of America equal 163,000 square miles, or 33 times our quantity, and nearly untouched.

[2] The lower coal-measures are the chief repositories of the ironstones of the basin (Merthyr Tydvil on the north, Taff Vale on the south). The beds are about 5 inches thick—metallic iron, 40 per cent.; containing marine shells, fish, and plants.

trating the coal-measures through this overlie. The lowest member of the Trias is here termed the "Dolomitic conglomerate," the "overlie" of the coal-miner. This conglomerate overlaps all the older series of rocks in the coal-basin. The thickness of the *coal-measures* in the southern area is not less than 5000 feet, containing 51 seams, and about 100 feet of coal; only 20 seams out of the 51 are upwards of 2 feet in thickness, affording in reality about 70 feet of workable coal. This basin is separable into an upper, middle, and lower series of strata or measures,—the upper series, 1800 feet thick, containing 10 seams of coal, and about 18 feet of fuel; the middle, or Pennant grits, 1500 feet thick, with 5 seams of coal and 10 feet of fuel (little worked); and the lower shales, 1600 feet thick, with 36 seams of coal and 70 feet of fuel. The whole of the coals are bituminous, though steam coal occurs in the lower series at Kingswood. No anthracite or cannel coal is known over any portion of the area. Gas coals occur in the northern portion of the basin at Coal-pit Heath and Parkfield, the latter being extensively worked for this purpose.[1] A remarkable feature in the physical structure of this coal-field is the great central band of rock called the "Pennant," upwards of 1500 feet in thickness, which divides the lower coal-bearing measures from the upper series; it is a constant feature throughout the basin. No shafts have ever penetrated the lower coal-measures through the Pennant, and perhaps years may elapse ere the attempt will be made, its thickness and water-bearing character forbidding it. Economically, this Pennant rock is of great value when exposed at the surface.[2] The upper coal series of Radstock and Farrington Gurney contain the finest bituminous coals, *but are extremely thin.* The Radstock beds, containing 6 seams, unitedly do not possess 12 feet of coal. The Farrington beds, 600 feet lower, contain 4 seams in all, about 10 feet thick; little or no waste occurs, the coals being good throughout. It may be truly stated that nowhere else in Britain are such thin seams worked,[3] or to better profit.

The succession in the southern basin or area is as follows:—

Upper	1st series, Radstock—6 seams, 11 to 12 feet of coal, 1200 feet of strata.	
	2d series, Farrington[4]—4 seams, 6 to 12 feet of coal, 800 feet of strata.	
Middle—Pennant grit, 1500 feet.		
Lower	3d series, Bedminster beds	20 to 36 seams and 60 feet of coal, 1600 feet of strata.
	4th or lowest, Vobster „	
Millstone grit—No coals, 1000 feet of strata.		

[1] These are the lowest coals in the *upper series* here, and are immediately above the "*Pennant*," which divides the lower from the upper coal-measures over both areas of the coal basin.

[2] This Pennant rock occupies the same geological position in South Wales, there determined by the position of the Mynydd-Isalwyn coal-seam and the Hughes vein.

[3] Some little more than one foot in thickness.

[4] These seams are worked at Parkfield, in the northern basin, where they are fine gas coals. The first upper, or Radstock series, do not occur at Coal-pit Heath or Parkfield.

The lower series of coals are worked only along or around the outcrop or edges of the coal-basin, as at Yate and Kingswood, in the northern area, and Bedminster, Twerton, Mells, Vobster, Ashton, &c., in the southern; the extreme depth (5000 feet) and the "Pennant rock" forbidding any attempt to win coals in the centre of the southern area. The whole of the northern area or northern part of the coal-field at Kingswood has been elevated higher than the Somersetshire end of the basin, and has, therefore, been more denuded away. Only four workable coal-seams occur in the northern area. In the southern or Radstock basin six seams occur.

The Bristol coal-field, although not the most easterly in England, appears nevertheless to be most nearly related to, if not connected with, the western portion of Europe through the probable extension of the coal-fields of Belgium (Mons, Valenciennes, &c.) The line of connection or axis may be through or along the Mendip Hills, eastward to Belgium (axis of Artois). It is conjectured that eastward of the Bristol coal-field another coal tract may occur under the south-eastern counties of England (Kent and Sussex), having direct connection with the Belgian deposits. This question formed an important item of inquiry by the Royal Commission.

The resources of the Bristol coal-field are extensive, but large deductions must be made for the disturbed and folded strata on the south side of the basin, for the great depth at which coals lie buried, and also for the thinness of many of the seams, which renders them unavailable at great depths. No coal-field in Britain has strata so disturbed through faulting and dislocation. The whole series is compressed into a comparatively narrow trough from east to west, and the southern area has received great north and south flexures. In the Mendip area the coal-seams are vertical or even overthrown. Thinner seams are worked in the Bristol basin than in any other coal-field in Britain.

Looking at the future of the Bristol coal-field, based *upon the present yield* or output, there is coal enough to last nearly two thousand years. It must be borne in mind, however, that, considering its capabilities, the resources are little drawn upon, and the coal-field is capable of yielding five times the quantity now withdrawn from its great store. The original quantity of coal, according to Professor Hull, after the necessary corrections for denudation, is estimated at 4148 millions of tons. Deducting from this one-third for inaccessible and spoiled coals, and one-tenth for those worked out, with the usual restriction as to depth (4000 feet), we have stored away for future use in this coal-field 2000 million tons of available fuel. The present output is only 1,000,000 tons, the produce of thirty-four collieries.

The following estimate, however, by Professor Prestwich, in his Report upon this coal-field for the Royal Commission, differs from that of Professor Hull, and is the result of a more recent and searching survey:—

Estimate of Coal in the Bristol Coal-Field.

1.	The quantity of coal at a less depth than 1500 ft.	.	1,718,791,280 tons.
2.	„ „ between 1500 ft. and 3000 ft.	.	1,519,997,981 „
3.	„ „ „ 3000 ft. and 6000 ft.	.	2,227,531,577 „
4.	„ „ „ 6000 ft. and 8000 ft.	.	637,990,144 „
			6,104,310,982 tons.

From this we must deduct about 2000 million tons for the quantity below 4000 feet (the limit of calculation), this correction leaving more than 4000 million tons for future use. Much coal is concealed beneath the estuary of the Severn, between Chepstow and Portishead, thus tending still more to show the original connection of the South Wales and Bristol coal-fields. Space will not allow us to enter into further details relative to the structure of this complicated, rich, and interesting coal area.

11. *Forest of Dean Coal-Field.*

This complete and physically typical coal-field lies between the rivers Severn and Wye. In form, outline, and geological structure, it is more perfect than any other coal-field in Great Britain. The coal-measures in their best developed condition are 2760 feet thick; they contain fifteen seams of coal.[1]

Sir Henry de la Beche gives the following section[2] showing the thickness of the several stratigraphical divisions:—

Coal-measures with fifteen coal-seams . . .	2765 feet.
Millstone grit	465 „
Carboniferous limestone	480 „
Lower Carboniferous shale	165 „
Old Red Sandstone	8000 „
	11,875 feet.

The total area amounts to 302,760 acres; the available supply or quantity of coal yet untouched to 260,000,000 tons, or sufficient to last about 350 years at the present rate of exhaustion of 760,000 tons per annum.

[1] All the fifteen coal-seams bear the name of "Delf," *e.g.*, "*Little Delf*," "*Rocky Delf*," "*Whittington Delf*." The thick sandstones that occur between the Churchway and Coleford High Delf coal-seams are probably the "Pennant rock" that occurs between the Lower and Upper Coal-measures in the Bristol coal-field in the Forest of Dean. They are 900 feet thick.

[2] Mem. Geol. Survey, vol. i. p. 203.

CHAPTER XXIII.

CARBONIFEROUS STRATA OF SCOTLAND AND IRELAND.

Scotch Carboniferous Rocks.

The Carboniferous system of Scotland is capable of division into four series of strata in descending order. They are as follows:—

4. Coal-Measures.	Upper Red Sandstones, clays, and marls. White and grey sandstones, shales, fire-clays, clay ironstones, coal-seams, &c. (comprising the Flat-Coal Group of Midlothian).
3. Moor Rock or Millstone Grit Series.	White and grey, sometimes reddish, sandstones with some thin coals.
2. Carboniferous Limestone Series.	Upper thin limestones. Sandstones, shales, fire-clays, coal-seams, &c. (the Edge-Coal Group of Midlothian).
1. Calciferous Sandstone Series.	White and grey sandstones, dark grey, blue or black shales (sometimes highly bituminous and forming oil shale), one or two coal-seams, cyprid limestone, and cement-stones. Lower Red Sandstones and Cornstones.

1. **Calciferous Sandstone Series.**—This name has been adopted by the Geological Survey to designate the Scottish type of Lower Carboniferous rocks intervening between the base of the Carboniferous Limestone and the top of the Upper Old Red Sandstone. The beds are chiefly composed of sandstones and shales in two well-marked series. The *lower* is made up of red and reddish-grey sandstones fully 1500 feet thick.

The *upper group* is more variable both in thickness and character; at its maximum it is not less than 2000 feet. The well-known sandstones of Craigleith and Granton, with the limestone of Burdiehouse and the shales of Wardie, occur in this group. Most of the fossils found indicate the proximity of land during the deposition of the strata, consisting chiefly of land plants associated with *cyprids*, and the *scales*, *teeth*, *bones*, and *coprolites* of Ganoid fishes, all estuarine in habit and character. In connection with the upper group of the Calciferous limestone, there is evidence of volcanic phenomena in the form of numerous intercalated small sheets of basalt rock and tuffs. Still further east, in the Garlton Hills, north of Haddington, there occurs another and distinct volcanic area belonging to the Calciferous period. But instead of small independent and separated cones of tuff or basalt, we have here a large area of bedded porphyrites and tuffs, covering a space of more than forty square miles, and more than 1000 feet thick.

2. **Carboniferous Limestone Series.**—The Scottish type of this formation differs materially from the massive limestone of Central England. It consists of white and grey sandstones, dark shales, fire-clays, coals, and a few limestone bands, grouped under three divisions:—

(c.) The Upper Limestone Group.
(b.) The Edge Coal Group.
(a.) The Lower Limestone Group.

Palæontologically, they agree entirely with the English Carboniferous Limestone.

The Middle or Edge Coal group is about 600 feet thick, and consists of shales, sandstones, and fire-clays, with twenty-six seams of coal above one foot in thickness. These are the "Edge Coals," so called on account of their steep inclination against the extensive fault that flanks the south-east side of the Pentland anticline.

The Upper Limestone Group consists of sandstones, shales, and fire-clays about 700 feet thick, with three or four seams of coal.

Coal-measures.—The highest division of the Edinburgh coal-field consists of 1200 feet of sandstones, shales, and fire-clays, with twelve workable seams of coal. These coal-measures probably represent the lower part of the English coal series.[1]

Scotch Coal-Fields.

The peculiarity and value of the Scotch coals, and the physical condition of the coal-fields, are so important in any inquiry bearing upon the question of their geology, that it is impossible to pass over such areas as the Clyde basin, Midlothian, and Haddington, differing as they do in many respects from the English deposits.

The Carboniferous rocks of Scotland cross the country from south-west to north-east, and stretch from sea to sea—from Ayr to the Firth of Forth—occupying the great synclinal hollow or trough along the valley, and parallel to the chains of the Grampians and Lammermuirs, or between the slopes of the Grampians and the north flanks of the southern uplands. This great hollow or depression is filled with a coal-field nearly 100 miles long, extending from St. Andrew's, near Greenock, and from Dalkeith to Ayr, and about 25 miles broad. This extensive range, however, is not all productive of coal, hence we have six distinct fields or basins, viz., the coal-field of the Clyde basin, the Midlothian, Edinburgh, and Haddington coal-field in one, and the coal-fields of Fifeshire, Clackmannan, Ayrshire, and Lesmahagow. The greater part of the workable coal series of the Scottish area is included in the Carboniferous limestone group. The English Lower Carboniferous rocks undergo a gradual physical change in their extension from south to north, or from the Midland Counties into Northumberland and South Berwickshire, and coal-seams occur in, and are worked in them near the base, associated with thick beds of shale, the calcareous condition having greatly diminished. Below the equivalents of our Carboniferous limestone are a series of white and grey sandstones, shales, cement stones, and thin coal-seams. These equal the English Lower Limestone shales, and, as before

[1] See "Geology of the Neighbourhood of Edinburgh" (Map 32), H. H. Howell and A. Geikie (Mem. Geol. Survey of Great Britain, 1861), and Appendix by J. W. Salter.

stated, are termed "calciferous sandstones," and sometimes attain a thickness of 4000 feet. The general sequence is that of the south, viz.: 1. Coal-measures; 2. Millstone grit; 3. Carboniferous Limestone series; 4. Calciferous sandstone. The first, third, and fourth are the chief coal-bearing groups.

Clyde Basin Coal-Field.

This magnificent coal-field, which includes the greater part of four counties, is traversed throughout its entire length by the Clyde. The coal-bearing series of Lanarkshire are 4000 feet thick, divided into upper, middle, and lower groups, respectively 840, 960, and 2200 feet thick, the base of the whole being the calciferous sandstone. The upper and lower series are the chief coal-bearing groups. The upper has ten seams of coal above 2 feet thick, and three rich bands of ironstone. The lower series contains valuable beds of coal, and three courses of black-band ironstone. "West of Glasgow, the black-band ironstones occasionally pass into coal-seams, the carbonaceous matter gradually replacing the argillaceous carbonate of iron." (Hull.)

Valuable beds of cannel and oil shales occur west and south of Glasgow, and the far-famed "Boghead" brown cannel, or parrot coal, the richest in oil and solid paraffin in Scotland (20 inches thick), rests upon a bed of fire-clay (under-clay), with *Stigmaria ficoides* ramifying through the under-clay—conclusive evidence of this coal, like all other seams, having accumulated on the spot now worked. The small and detached basin of Lesmahagow contains, and is celebrated for, rich cannel or gas coal, near the base of the limestones, and may be the same as the Glasgow series. This Boghead cannel yields 13,500 feet of gas per ton, 36 per cent. of coke and ash, and 20 per cent. of hydrocarbon. This remarkable variety of coal occurs also at Torbane, Inchcross, Bathvale (near Bathgate), Rocksoles (near Airdrie), Pirnie, Kirkness, and Wemyss in Fife; also in the county of Linlithgow, where it reaches 30 inches in thickness. Close and compact cement-stone and shale compose the roof of this coal. The produce is about 100,000 tons per annum. Marine fossils occur in the black-band ironstone and oil shales, which occasionally overlie the cannel. The upper series contain both fresh-water and marine fossils; the lower series are entirely marine, and are rich in fish, mollusca, and other invertebrata.

Mid-Lothian, Edinburgh, and Haddington Coal-Fields.

The proximity of this triple field to the Scotch metropolis, and its now isolated position on the south-western side of the Firth of Forth, which divides it from the Fifeshire field, adds interest to its otherwise great value, physically as well as economically. This and the Fifeshire coal area are the most interesting of all the Scotch fields; the great beds, sheets, or flows of contemporaneous and intrusive igneous rocks, with their effects or action upon the associated

Carboniferous sandstones, limestones, coals, and shales, must be seen to be understood.[1] There are in this field nearly fifty coal-seams, varying from 1 foot to 13 feet each, and having an aggregate of 120 feet of coal. Celebrated amongst other coals are the 8-feet "great seam," and the "North Greens," the latter being 1500 feet below the "great seam," and yielding the well-known "Parrot" 3-feet coal, so highly esteemed for its gas. Both these seams occur in the Carboniferous limestone, which is here 1600 feet thick, and contains seventeen workable coals; the coal-measures proper above, with eleven seams, being 1220 feet, with the millstone grit at the base. The East Lothian field, 30 miles square, with 10 seams of coal, is composed entirely of the Carboniferous limestone series, which encircles the field on the east and south-east; and the coals and ironstones throughout are the equivalents of the "edge coals" of the Mid-Lothian; the "calciferous sandstones," and the Burdiehouse or Queensferry limestone, with its rich fauna and flora, underlie the limestone group. Volcanic ashes and associated contemporaneous igneous rocks accompany the "calciferous" beds.

Fifeshire and Ayrshire Coal-Fields.

More remarkable still is the *Fifeshire coal-field*, on the north side of the Firth of Forth. Gas, steam, iron-smelting, and anthracite coal-seams, 29 in number, and of high quality, range through the measures, and enter the sea near Kirkcaldy.[2] At Burntisland and along the coast eastward, associated with the calciferous beds, are to be seen and examined the "necks or remnants of old submarine volcanoes, which (during Miocene times) poured forth their molten lavas near the sea bottom or bed, and vomited forth showers of ashes, stones, and blocks, even now to be identified as isolated bosses of basalt, tuff, and agglomerate."

The Ayrshire coal-field, separated from the Clyde by the Dunlop Hills and Trappean and Devonian rocks, is a rich and productive area; "great part, however, of the minerals has been destroyed through the agency of intrusive igneous masses, and dykes of dolerite and basalt, which also interfere with the prosecution of mining operations." About 35 feet of coal and much black-band ironstone occur, chiefly in the lower part of the coal-measures and the limestone series.

Lastly, we must refer to the little isolated and abnormal *coal field of Brora*, on the east coast of Scotland, on the shores of Dornoch Frith, and near Golspie and Dunrobin Castle. The age of this coal and its associated strata has often been discussed. There cannot, however, be any doubt that the coal-seam itself is of Lower Oolitic age; its richly fossiliferous roof is crowded with Middle Oolite species in vast quantities, the bottom portion being the Middle Oolite or Kel-

[1] Consult the able Memoir upon this field by Messrs. Geikie and Howell, Mem. Geol. Survey, Sheet 32 (Geol. of the Neighbourhood of Edinburgh).

[2] Langdale, "Transactions of the Highland Society," vol. xii.; Hull, "Coal-Fields," &c., p. 286.

laway rock. The seam contains a fauna referable only to this horizon, being purely marine, and containing 60 known species of fossils. The main bed of coal is from 2 feet 6 inches or 3 feet to 3 feet 6 inches thick, and rests upon beds of black carbonaceous shales, containing thinner seams of coal or coaly matter, and yielding good oil. The series of shales, &c., below the coal-seam, are estuarine and inconstant in character. Many fresh-water and estuarine shells, such as Unio, Cyrena, Ostrea, &c., occur, and crushed stems of "*Equisetites columnaris*" are abundant through the coal.

We thus see that the geological age of the Scottish coal-fields and coals was earlier in time than that of England. Scotland was an old estuarine land-surface prior to most of the accumulations and coal growths more to the south. In other words, much of the north, middle, and west of England *was depressed* beneath the seas when the Clyde field, the Lothians, Edinburgh, and Haddington series, 1200 feet thick, with 12 seams of coal,—the Fifeshire coal-field, with its 21-feet Dysart seam, and three others 10 feet thick,—also the Clackmannan shales, with the gas, parrot, and iron-smelting coals, *were probably in existence.*

TUEDIAN BEDS.[1]—Under this name are grouped the lowest Carboniferous beds, which in Scotland are termed the "*Calciferous Sandstones.*"[2] The lower portion of these sandstones passes down insensibly into the upper part of the Upper Old Red series. In Northumberland, the upper limit of the "Tuedian beds" is equally indefinite, merging into the succeeding series, or Carboniferous limestone proper (in the north); no hard line can therefore be drawn either at the base or top of the Tuedian or Calciferous beds. Notwithstanding this, these rocks have a distinctive character of their own. The sandstones, of which they consist to a considerable extent, are not unlike those of the succeeding Bernician, except towards the base of the series, where they usually contain rolled fragments of the Cheviot porphyrites.

The lower limit of the Tuedians is defined by the outline of the Cheviot range and its rocks, which had been erupted, and stood as an island in the lowest Carboniferous or Upper Old Red Sandstone sea. The upper limit is not so easily traced. Practically, the Tuedian rocks begin in descending order where the limestones of the Bernician series lose their usual Carboniferous limestone type.

North of Berwick, the lowest Bernician limestone is the "Dun limestone." The coast at Lamberton for some miles is occupied by this rock, which is rich in organic remains, and may be taken as the line separating the Tuedian from the Bernician or Lower Carboniferous Limestone. Purple and greenish marly shales, containing amorphous siliceous concretions, are characteristic of the Tuedian beds near Holystone and Sharperton, &c. Few or no *marine fossils* occur in these Northumberland Tuedians. The sandstones abound in *Sigillariæ*, *Calamites*, and *Lepidodendra*, and the genus *Ulodendron* (?) is plentiful.

THE BERNICIAN ROCKS.—This series essentially consists of numerous beds of limestone grits and sandstones of every texture, of shales of every character, and of coals, with and without underlays, comparable in every way with those of the Upper Carboniferous series. The thickest beds of limestone seldom exceed 30 feet; this, however, varies in different places. The entire thickness of the series in the Alston Moor district, south of Northumberland, is about 2500 feet, and in the north of the county (the Alnwick and Scremerston district) nearly the same;

[1] The name "Tuedian," proposed by the late Mr. George Tate in 1855, is geographical, and derived from that part of Britain in which the rocks it denotes are most largely developed.

[2] A name given by Maclaren in 1839.

whilst between these two regions, or in the tract of country lying between the Tyne and the Coquet, the maximum thickness is at least 8000 feet. This great thickening of the lower Carboniferous rocks in the centre of Northumberland has a marked influence in the physical history and geological structure of the county. In this area of greatest thickness many changes take place in the condition of the beds; new limestones appear; the grits and sandstones are inconstant; thick crag-making beds dwindle away in a short space, being replaced by shales of equally uncertain character; and the continuity of the coal-seams exhibits greater tendency to split up and thicken or thin out in shorter distances than in the coal-measures.[1]

TABLE XXVII.—*Showing the Correlation of the Bernician and Tuedian Series.*

Northumberland.			Synonyms.	
Carboniferous	Upper	Coal-measures	Coal-measures	Upper coal-measures.
		Ganister beds	Ganister beds	
		Millstone grit	Millstone grit and Carboniferous limestone in part.	Middle Carboniferous.
	Lower	Bernician group	Yoredale series and Calcareous group in part.	
			Scar limestone series and Calcareous group in part, *plus* Carbonaceous group.	Lower Carboniferous.
		Tuedian	Calciferous sandstone, or Tuedian, or Valentian, and Upper Old Red Conglomerate in part.	

Carboniferous Rocks and Coal-Fields of Ireland.

We now pass to Ireland, the half of which is occupied by rocks of the Carboniferous system. These, if viewed on a large scale, offer the same general features as the great English and Welsh groups.

Little, however, can be said relative to the coal of Ireland, as compared with the richer stores of England and Scotland. The time was when Ireland was two-thirds covered by coal-measures; now, only a few (six) isolated tracts or outliers are left as evidences of former wealth, nearly all the coal-measures having been denuded from the limestone and other "bases," leaving the great central Limestone plain of Ireland a coalless tract beneath the drift. The six isolated coal-fields in Ireland—Antrim, Dungannon, Tipperary, Tyrone, Kilkenny, and Clare—are remnants of a once widely-spread and extensive formation, the lower portions only being left. In the south of Ireland, about Cork, the coal-measures are almost the same in section as those at the western extremity of South Wales, and the coal of this southern district is chiefly anthracite, whereas the coal-measures of the north of Ireland, Tyrone, and Ballycastle, are bituminous, like those of the north of England; but no correlation can be attempted. All the Irish collieries united, about forty in number, do not yield

[1] For marked and special features, see "Geology of Northumberland."—Lebour. Also, Tate, "Geology of the Roman Wall," published in Bruce's Handbook or Guide.

more than 150,000 tons per annum; while the net available coal left for future use in Ireland is estimated at 180 millions of tons. There is a greater quantity of anthracite coal raised than of bituminous. The peat of the bogs may yet be converted into coke. It is unsurpassed in extent and quality.

The great area of the Irish Carboniferous system thus, unfortunately, yields but little coal, the upper and more generally productive portion (Yoredale) being perhaps only recognisable about Dungannon and Ballycastle. Most of the coal about the source of the Shannon, near Kilkenny and Newcastle, is of the age of the millstone grit, or of the lowest part of the coal-measures. The greater part of the area is occupied by the yellow sandstone, carboniferous shales, and the Kulkeagh shales, &c.[1]

Occupying the picturesque coast of Donegal Bay, Sligo Bay, and Killala Bay, and skirting the mountains of Connemara, the Carboniferous system ranges along the coast at Galway, and keeps it nearly to Dingle Bay. From this point, retiring inland, westward by Killarney to Mallow and Fermoy, it throws out branches and outliers to Kenmare, Clonakilty, Kinsale, Cork, Rathcormack, Dungarvan, Waterford, and Wexford; but the main outline turns again northward, skirting the mountains of Wicklow and Dublin, to the sea-coast near the capital. It leaves the coast again near Drogheda, turning inland to Slane, Cavan, Monaghan, Armagh, and Donegal, and throwing off long digitations to Omagh, Maghera, and Lough Foyle, and outliers to Strangford Lough, Dundalk Bay, and Kingscourt. This immense field is broken by the older ridges of the Galtees, Tipperary, and other inland mountains. It is about 150 miles square! The result of Sir Richard Griffith's long labour on the Carboniferous system of Ireland is indicated by the following summary:—

The coal-measure series but slightly represented.
Millstone-grit series. It occupies a large space about the source of the Shannon, crowning with its huge blocks and crags the heights of Kulkeagh, and yielding coal, ironstone, and furnace grits to the iron-works on the western side.—500 feet.
Great shale series of Kulkeagh, with *goniatites*, *posidonomyæ*, *orthoceratites*, *bellerophons*, &c.—600 feet.
Upper limestone, cavernous, with coral bands in several stages.
The calp series, grey and dark limestone, with shale and sandstone interposed in some districts.
Lower limestone.
Carboniferous shale, locally rich in *spiriferæ*, *strophomenæ*, fish-remains, &c.
Yellow sandstone, with shale and occasionally limestone.

The upper parts of the series (the millstone grit and coal-measures) are most conspicuous in the country about Lough Erne and the sources of the Shannon, about Kilkenny and Castle Conner, and in the elevated country on each side of the estuary of the Shannon. The true limestone series is of grand and amazing extent in the central

[1] *Vide* Kinahan, "Manual of the Geology of Ireland," pp. 50–129, for a complete and able description of the Carboniferous rocks.

parts of Ireland; and the lower series arrives at its greatest importance in the southern tracts about Cork and Kinsale. In Kilkenny county, at Knocktopher, the limestone rests on dark shale and yellow and brown sandstone, 150 feet thick. (Below these are red slates, and red and green argillaceous sandstone, with ferns of the genus *Sphenopteris, Cyclopteris, Palæopteris*, and Fish, which occur associated with the fresh-water bivalve *Anodonta*.)

Near Carrick-on-Suir there occur, below the limestone, thin-bedded yellow sandstone, and green and yellow shales, 150 feet (then alternations of yellow sandstone and hard red shale, 350 feet, unequivocal Old Red Sandstone, &c., below 1800 feet).

Farther west, in the same county, the upper beds of yellow sandstones and red shales thicken to 900 feet (the whole series, including Old Red, 4500 feet). In the northern part of the county of Cork, yellow sandstones occur, alternating with red shales and slates, 500 feet. South of Cork the series is thicker and more varied.

The coal-fields of Ireland, if we include in this term the millstone grit, occupy large tracts, and are upon the whole analogous in general mineral characters and organic contents to those of England. The same absence of limestone, the same kind of succession of sandstones and shales, are remarked in them. Anthracite or stone coal, like that of South Wales, abounds in the Leinster and Munster districts; bituminous coal occurs in Connaught and Ulster. In Ulster the principal collieries are at Coal Island and Dungannon. The Munster coal district is of greater extent than any English coal-field, but is much less productive.

In Kerry and Limerick, in the province of Munster, the Carboniferous formation seems to be best developed, if we except Tyrone and Fermanagh. The following table gives the general classification of the Munster rocks, to which most of the carboniferous rocks of Ireland may be referred:—

Classification of the Lower Carboniferous Rocks of Limerick and Kerry.

4 *b.*	Upper limestone of the Burren type.	Bedded limestones having in places inliers of sandstone and shale. Cherty zone.
4 *a.*	Upper limestone of the calp type.	Earthy limestone, sandstones, and shales, having in places coal rods or coaly seams. Cherty zone.
3.	Lower limestone.	Fenestella limestone (Wynne). Lower cherty zone. Lower shaly limestone.
2.	Lower limestone shale.	
1.	Old Red Sandstone, or lower carboniferous grits and shales	Red, purple, green, yellow shales and clay rocks, with some grits and sandstones. Principally red and yellow grits, sandstones, and conglomerates, with subordinate shales and clay rocks.

[1] Kinahan, *op. cit.*

Lower Carboniferous Rocks.

In the Dingle promontory the Lower Carboniferous rocks, which lie unconformably on the Dingle beds, have the following thickness :—

4.	Coal-measures	
3.	Limestone	1800 feet.
2.	Lower limestone shale	400 ,,
1.	Old Red Sandstone or Lower grits and shales .	4000 ,,
		6200 feet.

Limerick.—In the county of Limerick and the adjoining portion of Tipperary there are well-marked divisions in the Carboniferous rocks.

The following general section, given by Mr. Kinahan, shows the sedimentation of the entire series :—

Upper limestone of Burren type .	Bedded limestone . . .	240 feet.
	Cherty zone	20 ,,
Upper limestone of calp type . .	Limestone and shales . .	1000 ,,
	Cherty zone	40 ,,
Lower limestone .	Fenestella limestone . . .	1900 ,,
	Lower cherty zone . . .	20 ,,
	Lower shaly limestones . .	280 ,,
Lower limestone shale		100 ,,
Basalt or Old Red Sandstone		2000 ,,
		5600 feet.

Interstratified with these rocks in the counties of Cork, Limerick, and Clare there are zones of eruptive rocks, the best developed being at the junction of the "*Fenestella and upper limestone.*"

The fossils in the lower limestones are very numerous individually, but few in species. The following are the chief forms :—

Fenestella flabellata, Orthis Michelini, Spirifera striata, Streptorhynchus crenistria, Strophomena analoga, Acroculia vetusta, Nautilus dorsalis (rare), *Actinocrinus costatus, A. polydactylus,* and *Platycrinus lævis.*

In the LOWER SHALY LIMESTONES fossils are abundant. One of the most marked is the coral *Michelinia favosa,* giving name to the shaly limestone (*Michelinia limestone*). The following occur :—*Cyathophyllum ceratites, Lithostrotion junceum, Ceripora gracilis, Fenestella flabellata, Glauconome grandis, Orthis Michelini, O. resupinata, Producta margaritacea, P. semireticulata, Rhynchonella pleurodon, Spirifera cuspidata, S. glabra, S. lineata, S. striata, Streptorhynchus crenistria,* and *Phillipsia pustulata* (rare).

The LOWER CHERTY ZONE constitutes a marked base to the *Fenestella limestone,* in which occur *Terebratula hastata, Spirifera striata, Rhynchonella pleurodon, R. pugnus, Orthis resupinata,* and *Producta semireticulata.*

Aviculopectens and *Cardiomorpha oblonga,* with species of *Edmondia* and *Pleurorhynchus,* are the most abundant Pelecypoda. *Euomphalus pentangulatus, Natica elliptica, Euomphalus Dionysii, Turritella suturalis, Trochella prisca,* and *Loxonema Lefeborei* are the chief Gasteropoda. *Nautilus biangulatus, N. dorsalis,* and *Goniatites sphæricus,* are the common Cephalopoda. Fossil remains are rare in the "Calp" as compared with the Fenestella limestone. The Heteropoda, through the *Bellerophons,* are numerously represented, associated with *Phillipsia derbiensis* and *P. pustulata, Chonetes papilionacea,* and *Producta mesoloba.*

Leinster.—"In part of Kildare, in Dublin, Meath, and Louth, limestones of the Calp type are the chief representatives of the Lower Carboniferous rocks.[1]

"South-east of Thomastown at Kiltorcan is the famous quarry in which the fine *Adiantites* (*Palæopteris*) *Hibernicus*, *Sphenopteris Hookeri*, *Anodonta Jukesii*, *Coccosteus*, and *Bothriolepis* occur. An assemblage of fossils, similar to those of Kiltorcan, is found in the yellow sandstones near Fallow Bridge, County Waterford, and near Toe Head, County Cork."

Clare and Galway.—"The general section of the rocks in south-east Clare is similar to that of Limerick, except that the Old Red Sandstone, the Lower Limestone, and the Calp, are thinner, and the Upper Limestone of the Burren type, as followed northward, rapidly thickens.

"The Old Red Sandstone, the Lower Limestone Shale, and the Lower Limestone, do not occur north of the parallel of Galway in the central parts of Ireland, but in South Ulster towards the north-east they again appear. The Calp of Galway and that of North Leinster are probably connected; their connection is hidden by the great head of drift and bog in the intervening country. The Upper Limestone abounds in corals, the most typical of which are *Lithostrotion affine*, *L. junceum*, *L. striatum*, and *Alveolites depressa*."[2]

The following is the general section of the limestones of Clare and Galway:—

Burren Limestone	Bedded limestone with chert layers	1500 feet.
	Cherty zone	40 „
Calp	Black limestone shale, &c. Cherty zone	400 „
Lower Limestone	Fenestella limestone	300 „
	Lower cherty zone	100 „
	Lower shaly limestone	400 „
Lower Limestone shale		150 „
Old Red Sandstone		1000 „
		3890 feet.

Donegal, Londonderry, Antrim, Tyrone, and Armagh.—In the county Armagh the limestone rocks are of special interest, it being from them that the great collection of fossil fish (many of which form the types figured by Agassiz in his "*Recherches sur les Poissons Fossiles*") was obtained. Some of the Armagh fossil fishes are also found in the calp of Londonderry, Ballycastle (Antrim), and in the Burdiehouse limestone, Scotland. They are *Gyracanthus formosus*, *Psammodus porosus*, *P. rugosus*, *P. cornutus*, and *Cochliodus magnus*.[3]

[1] Exhaustive lists of fossils collected in Dublin and the neighbouring counties are given by Mr. Baily and Professor Jukes in the Explanations to Sheets Nos. 102 and 112 of the Geological Survey Maps of Ireland. Consult Kinahan, *op. cit.*, pp. 95–129.

[2] Kinahan, *loc. cit.*

[3] A list of these fish is given by Colonel Portlock in his Geological Report on Londonderry, Tyrone, &c., p. 461. These types are now in the National Collection in the British Museum, Cromwell Road, London. They were formerly in the possession of the Earl of Enniskillen and Sir Philip Egerton.

Upper Carboniferous Rocks.

(*Coal-Measures.*)

All attempts to strictly correlate the Irish coal-measures, stratigraphically, lithologically, and palæontologically, with those of England have failed. "If the *fossil fauna* alone is considered and the flora ignored, a forced correlation may be made with the lower coal-measures of England, but if the flora alone is taken into account and the fauna ignored, the measures may be made to seem of the same age as the upper coal-measures of England."—(Baily.) Kinahan[1] follows by stating that "from the uppermost beds of the upper limestone to the highest bed of the coal-measures found in Ireland, *terrestrial*, *fresh-water*, *estuarine*, and *marine* fossils are mixed up together; it would therefore appear that the Irish coal-measures have a type of their own, or that they cannot be correlated with the English rocks, except, perhaps, some of them with the culm-measures of Devonshire." Nevertheless, "although the rocks of the Irish coal-measures vary irregularly amongst themselves, yet there are certain persistent differences amongst them extending over the whole of Ireland, which render them capable of being subdivided into three groups—the Upper, Middle, and Lower coal-measures."

The accompanying Table (XXVIII.) is taken from Mr. G. H. Kinahan's work. It embraces the main facts relative to the coal-measure rocks through the four provinces and the county of Cork.

Coal-Fields of Ireland.

The coal-fields of Ireland are divided into two groups, the line of demarcation being drawn from Galway Bay on the west to Dublin Bay on the east. North of this divisional line the coals are bituminous; in the southern area they are anthracitic, resembling those of the same latitude in the South Wales coal-field. The northern coal-fields are those of Leitrim, in Connaught and Tyrone, and Antrim in Ulster. The southern coalfields extend (*a*) through the counties of Clare, Limerick, and Cork, stretching both to the north and south of the estuary of the river Shannon; and (*b*) Queen's County, Kilkenny, and Tipperary, in which the Leinster coal-field, the most important in the south of Ireland, occupies an extensive tract.

I. *Northern Group of Coal-Fields.*

(a.) **Tyrone and Leitrim Coal-Fields.**—Bituminous coals are found in the northern group of the coal-fields of Ireland. The tracts of

[1] *Op. cit.*, p. 56.

TABLE XXVIII.—*General Section of the Irish Coal-Measures.*

	South-West Cork.	West Munster.	East Munster.	Leinster.	Connaught.	Ulster.
Upper Measures.	Not represented.	2050 feet. With an unknown number of coal-seams in the northern portion, and over six in the southern, or County Cork.	1295 feet. With seven regular beds of coal.	Thickness disputed.	Not represented.	About 900 feet. In which are eight or nine workable coals, also smaller local coals and thick beds of fire-clay.
Middle Measures.	Not represented.	1000 feet. To the north there appears to be a greater thickness than in the County Cork, where they seem to be about 900 feet.	900 feet.	800 feet. In these measures are beds of kelve and fire-clay, with a few coal rods.	600 feet. Represented. In which are three coals, one being a good workable coal.	1000 feet. With two seams of coal near the base. This thickness is a loose calculation, and probably too great.
Lower Measures.	200 feet. Represented. Coal-measure fish-remains in the lower beds.	500 feet. To the north, and about 700 feet to the south, coal-measure fish-remains in the lower beds.	600 feet.	500 feet. Coal-measure fish-remains in the lower beds, in counties of Meath and Louth.	600 feet.	600 feet.

most importance occur in the Leitrim district. Arigna and Altygowlan, west of Loch Allen, contain this variety of coal, and are the chief localities. At Arigna the main coal occurs at a depth of 110 feet. The beds of coal, three in number, occur partly in the Millstone grit, and in the mountain, Cuilcagh, reach an elevation of 2200 feet. The Tyrone coal-field is the most important in Ireland, the coal-measures being nearly 1000 feet thick. The Ganister beds are 1000 feet, the Millstone grit 200, and the Yoredale beds 600 feet. Bituminous coal occurs north of the town of Dungannon. The village of Coal Island occupies the centre of the coal-field. The coal-measures here are 2000 feet thick, and contain 24 seams of good coal,—eight seams, now worked, occur with middle coal-measures (*Coal Island series*), and two in the lower (*the Drumglass series*). All the coals are highly bituminous, and contain a high percentage of gaseous matter. The Ganister beds yield fish-remains—*Orthoceras*, *Goniatites*, *Productus*, and *Lingula* (*L. squamosa*).

(b.) **Antrim Coal-Field.**—At the northern extremity of Antrim occurs the small coal-field above named, yielding coals of a bituminous character.[1] The coal-field is about 4 miles in length, about 1½ mile in width, and nearly 600 feet in depth. The Carboniferous limestone is here only a few feet thick, its place being taken by sedimentary or mechanical deposits; whereas in Derbyshire it is a solid mass of limestone at least 5000 feet thick.

II. *Southern Group of Coal-Fields.*

(a.) **Leinster Coal-Field.**—The most important field in the south of Ireland yielding anthracite is that of *Leinster*, comprising, as stated, a large area of the Queen's County, Kilkenny, and part of Carlow. The Leinster coal-field is about 20 miles in length, and 14 in width.

(b.) **Tipperary Coal-Field.**—The isolated coal-field of Tipperary is about 20 miles in length from Freshford to Cashel, about 6 miles wide, and nearly 2000 feet thick.

(c.) **The Munster Coal-Field.**—This coal tract occupies a considerable area in the counties of Clare, Limerick, Cork, and Kerry. The chief localities are situated between the river Blackwater and Kanturk in the county of Cork. The coal of this field lies in a series of east-and-west troughs, parallel to the hills which strike in the same direction. The Coal-measures dip at high angles on either side, and are often perpendicular.

[1] The oldest colliery wrought in Ireland was at Ballycastle, but at a very remote period. There is no local tradition of the mine's history. The seams are worked under the sea.

Areas of the Coal-Fields of the United Kingdom.

	Coal-Fields	Area in square miles.
ENGLAND.	Durham and Northumberland	796
	Yorkshire, Derbyshire, and Nottinghamshire	800
	Cumberland	25
	Lancashire and Cheshire	220
	Leicestershire	15
	Warwickshire	30
	Shropshire	28
	North Staffordshire	75
	South Staffordshire	93
NORTH WALES.	Anglesea, Denbighshire, Flintshire	90
SOUTH WALES.	Monmouthshire 104, Glamorganshire 518, Brecknockshire 74, Caermarthenshire 228, Pembrokeshire 76	1000
	Gloucestershire (Forest of Dean)	34
	Somersetshire (Bristol)	150
SCOTLAND		1720
IRELAND		2800
	Total area	7876

The subjoined Table, by Professor A. Geikie, may be regarded as expressing the typical subdivisions which can be recognised with modifications in all parts of the country :—

Typical Subdivisions of Carboniferous Strata.

COAL-MEASURES.	Red and Grey Sandstones, clays, and sometimes breccias, with occasional seams and streaks of coal and *Spirorbis* limestone (*Cythere inflata, Spirorbis carbonarius*).
	Middle and chief coal-bearing series of yellow sandstones, clays, and shales, with numerous workable coals (*Anthracosia, Anthracomya, Beyrichia, Estheria, Spirorbis*, &c.)
	Ganister beds, flagstones, shales, and thin coals, with hard siliceous (Ganister) pavements (*Orthoceras, Goniatites, Posidonomya, Aviculopecten, Lingula*, &c.)
MILLSTONE GRIT.	Grits, flagstones, and shales, with thin seams of coal.
CARBONIFEROUS LIMESTONE SERIES.	Yoredale group of shales and grits, passing down into dark shales and limestones (*Goniatites, Aviculopecten, Posidonomya, Lingula, Discina*, &c.)
	Thick (scaur or main) limestone in south and centre of England and Ireland, passing northwards into sandstones, shales, and coals (abundant *Corals, Polyzoa, Brachiopoda, Lamellibranchiata*, &c.)
	Lower limestone shale of south and centre of England (marine fossils like those of overlying limestone). The Calciferous Sandstone group of Scotland (*Marine, Estuarine*, and *Terrestrial organisms*) represents the lower limestone shale and lower part of the English Carboniferous limestone, and graduates downwards insensibly into the Upper Old Red Sandstone.

TABLE XXIX.—*Geographical Distribution of the Carboniferous Rocks in Great Britain and Ireland.*

	Scotland.	Northumberland and Durham.	Lancashire, Derbyshire, and South Yorkshire.	South Wales, Central, and West of England.	Ireland. *Northern Series.*	Ireland. *Southern Series.*
Coal-measures.	Red Sandstone series—*No fossils.* Coal-measures—Coals, Shales, and Ironstones, *fossiliferous.*	*a.* Upper measures with thin coals. *b.* Middle measures with thick coals and plants. *c.* Lower measures or Ganister beds with thin coals.	*a.* Upper measures with Limestones and thin coals. *b.* Sandstones. *c.* Middle measures with thick coals. *d.* Lower measures or Ganister beds with thin coals.	*a.* Upper coal-measures with bed of Spirorbis Limestone in places. *b.* Pennant—Middle coal-measures S. Wales and Bristol coal-fields.	Upper and Middle coal-measures with thick coals. Lower coal-measures with *Marine Shells.*	Middle coal-measures with thick coals. Lower coal-measures with thin coals and *Marine Shells.*
Millstone Grit.	Sandstones and Ironstones—*Marine Fossils.*	A series of alternating Grits and Shales.	*a.* Grits and Shales. *b.* Flags (Haslington Flags). *c.* Shales, Grits, and Kinder-Scout Grit.	Solid Red and Grey fine-grained Grits and Conglomerates—(here and there thin beds of coal).	Millstone Grit.	Flagstone Series.
Yoredale Rocks.			*a.* Shales — Yoredale beds. *b.* Shales with thinly bedded hard fine Sandstones (Yoredale Sandstones). *c.* Black Shales with thin earthy Limestones.		*a.* Shales with Ironstones, Yellow Sandstones (Fermanagh).	Shale Series.

	Scotland.	Northumberland and Durham.	Lancashire, Derbyshire, and South Yorkshire.	South Wales, Central, and West of England.	Northern Series.	Ireland. Southern Series. S. W. Counties.	Ireland. Southern Series. S. E. Counties.
Carb. Limestone Series.	*Coals.* a. Upper Group—Marine with occasional brackish water deposits. b. Middle Group—Coals and Ironstones, few *Marine Fossils.* Shales. c. Lower Group—Coal, Marine.	Limestones with coals, Shales, Grits, and Sandstones.	Limestones and Shales.	a. Upper Shales and impure Limestones. b. Thick-bedded Limestones. c. Lower Limestone Shales, thin-bedded Limestones, and Sandy Shales.	b. Upper Limestone. c. Calp or Middle Limestone. Lower Limestone. Shales, Sandstones, and Conglomerates.	Carboniferous Limestone. Lower Carboniferous Slate with Coomhola Grits.	Upper Limestone. Calp or Middle Limestone. Lower Limestone. Lower Limestone Shales.
Calciferous Sandstone Series.	a Upper or Cement stone Group—Burdie House beds, and Wardie Shales. b. Lower Group—Red Sandstones and Conglomerates. Upper Old Red Sandstone—? Carboniferous.	Tuedian beds. White and Grey Sandstones with Greenish Grey Shales, Cement stones and Limestones.					

CHAPTER XXIV.

COAL-FIELDS OF THE CONTINENTS OF EUROPE AND AMERICA.

ALTHOUGH these fields are more scattered and disturbed than those of England, they may be similarly divided into two groups. The *first* group consists of those in which the series is complete, the coal-measures being symmetrically arranged upon the Carboniferous limestone and Devonian strata. Examples of this class occur along the line of coal-fields extending through the north of France and Belgium to the Rhine Valley, on the north side of the Ardennes. The *second* group is more numerous, and comprises coal-fields either contained in hollows in crystalline schists, or resting upon the older Palæozoic rocks, *e.g.*, the central and southern French basins, and those of Saxony and Bohemia. Further east, in Central and Southern Russia, the order observed in Scotland is reproduced, the coal being largely developed in the Carboniferous limestone.

Franco-Belgian Coal-Field.—The best-developed portions of this extensive field are seen within the territory of Belgium on the eastern side. The first field or basin is that of Liége, which extends from the Prussian frontier near Verviers for 45 miles in a S.W. direction; the greatest breadth being 9 miles near Liége.

The number of coal-seams is 83.
1. The upper series of 31 consist of flat coals, coking, and smith's coals.
2. The middle series of 21 are semi-dry or flaming coals.
3. The remainder, or lower series of 31, are dry or semi-anthracite coals.

Sambre.—Another important basin is that of the Sambre, which extends for about 30 miles from Namur to Charleroi; 9½ miles in width. At Montceau, near Charleroi, there are 73 seams varying much in condition.

Mons.—The most important development of the coal-measures in Belgium is in the basin of Mons, which extends from Mons to Thulin, 14 miles, with a breadth of about 7 miles, much covered by newer strata. The number of known coal-seams is 157, out of which 117 to 122 are workable, and few exceed 3 feet in thickness.

These seams are classified according to position into four groups. They are the recognised standard for the whole of the north of France and Belgium.

1. Upper series (*charbon fleuve*), 47 seams; occur chiefly near Mons; are rich bituminous coals.
2. Hard coals (*charbon dur*), 21 seams. These are soft coking coals.
3. Forge-coal series, 29 seams.
4. Dry coals, 20–25 seams, forming the bottom series.

This basin greatly resembles that portion of the Somerset coal-field immediately north of the Mendip Hills, the flexures and folds (due to compression) being of the same nature; but the Mons area, possess-

ing a larger development of coal-seams, exhibits these flexures to a greater degree, and sharply contorted into zigzag folds. At Mons, a single seam may be passed through six times in one pit 1050 feet deep, and the strata, which if flat would be 9 miles broad, are squeezed into a space 7 miles across, and about 8200 feet deep to the bottom of the basin. At Charleroi the compression is still greater, a breadth of 8½ miles of flat strata being narrowed to less than half that amount by contortion through lateral compression. The thickness of the overlying Tertiary and Cretaceous strata in the neighbourhood of Mons is from 500 to 900 feet; towards the French frontier the thickness is between 200 and 400 feet; and at Valenciennes about 250 feet. At Aniche, again, these overlying measures are 400 feet thick, below which the coal-measures are found to contain 23 feet of coal in 12 seams.

France.—"The coal-fields of Central and Southern France are mostly small in area and irregular in structure. The most important basin is that of St. Etienne and Rive de Gier, south of Lyons, on the right bank of the Rhone; it is 28 miles long, with a base of 8 miles. At Rive de Gier the three chief seams contain about 33 feet of coal, but at St. Etienne there are from 15 to 18 seams, making together about 112 feet of coal in a total depth of 2500 feet."

Saône et Loire, &c.—"The basin of the Saône et Loire, near Chalons and Autun, is about 25 miles long, in a S.W. and N.E. line. The coal-field of Alais and Grand Combe, near Nimes, is important, and has a total maximum thickness of 80 feet of coal. The Secondary and Tertiary coals of France are of small importance. Lignite is worked among other places at Dax in the Pyrenees, and at Treta and Fuveau near Marseilles."

Germany.—"The coal-fields of Germany, situated on the extension of the Franco-Belgian axis, are the two small basins of the 'Inde' and 'Worm' east of Adelnau, near Stolberg and Eschweiler, and the great Westphalian basin, east of the Rhine, in the valley of the Ruhr. This last is one of the most important in Europe, and extends for about 30 miles east and west from Essen to Dortmund. The breadth is unknown, but the beds are exposed for 15 miles. Cretaceous rocks cover the N. and N.E. portions. The greatest depth from the surface to the bottom of the basin is about 5000 feet. The coal is divided longitudinally by transverse axes of elevation into four principal basins. The total thickness of the measures is from 6000 to 8000 feet, and they possess 130 seams of coal, together amounting to about 300 feet. On the south side of the axis of the Rhenish Devonian strata (Eifel and Hunsruck range) occurs the Pfalz-Saarbrücken basin, which occupies a rectangular area, about 60 miles long by 20 broad, between Bingen, Donnersberg, Saarbrücken, and Mettlach. The productive portion of this coal-field is restricted to a triangular area of about 175 miles square in the S.W. corner. The Carboniferous limestone is absent, but the thickness of the true coal-measures is very great, the upper or Ottweiler series measuring from 6500 to 11,000 feet, with about 20 feet of coal, and the lower

or Saarbrücken series from 5200 to 9000 feet, with 82 workable and 142 unworkable seams. The total thickness is computed at 20,000 feet in the thickest known section."

"In the district between the Ems and the Weser there are the smaller coal-fields of Ibbenbüren on the easterly extension of the Westphalian basin, and also the Piesberg field near Osnabrück, which are of the true Carboniferous age. Coal-measures also occur in the Thüringerwald, the Schwarzwald, on the south side of the Harz, and in the Bavarian Oberpfalz."

Saxony.—"In Saxony there are two principal coal-fields, the Plauens'che Grund near Dresden, and Zwickau. The Plauens'che coal-field is chiefly interesting from the disturbed condition of its measures. The Zwickau coal-field is one of the most important in Europe; it forms an elliptical basin about 20 miles long between Zwickau and Chemnitz, and from 6 to 7 miles broad. The coal-measures are about 1700 feet thick, containing 12 principal seams of coal." Professor Geinitz has divided the series into three groups, according to the prevailing character of the associated fossil plants:—

1. Zone of Ferns, corresponding to the upper group.
2. „ Annularia and Calamites, or middle group.
3. „ Sigillaria, or lower group.

A fourth, or Sagenaria Zone, found in Silesia, corresponds closely to the culm-measures of Devonshire.

Silesia.—"The most important coal-fields of Eastern Europe are those of Silesia. The carboniferous limestone series, and the lowest coal-measures or culm strata, reappear in these basins, resembling the South Wales series between Swansea and Tenby.

"The coal-field of *Lower Silesia* and Bohemia forms a basin between Glatz, Waldenberg, Landshut, and Schatzlar, about 38 miles long and 22 broad; the coal-seams number from 35 to 50.

"*The Upper Silesian* coal district extends in disconnected masses from Mährisch-Ostrau in Moravia, in a north-west direction by Rybrik and Gleiwitz in Prussia, and Myslowitz in Poland; being held partly by Austria, Prussia, and Russia. The Prussian portion between Zralze and Myslowitz is the most important, extending over 20 miles in length by nearly 15 in breadth. The coal-measures are about 10,000 feet thick, the estimated thickness of workable coal 333 feet.

"The Tertiary coals, or lignites of Germany, are of considerable importance, occurring over large areas. The seams in places are of considerable thickness, although rarely continuous for any great distance. The chief deposits are situated in the lower parts of the valleys of the Rhine and Elbe in Nassau. The lignite district of the Rhine extends from near Bonn down to Deutz and Bensberg below Cologne."

Austria.—"The coal-fields of the empire of Austria-Hungary are of much interest from the diversity in their geological position. Coals of the Carboniferous age are chiefly confined to the northern provinces of Bohemia, Moravia, and Silesia; but in Hungary, and the alpine

lands in Styria, coals of Tertiary age are found which approach closely in composition and quality to those of the Coal-measures."

Pilsen.—The most important basin is that of Pilsen in Bohemia, which covers an area of about 300 square miles. It rests upon Silurian shale, and is unconformably covered by Permian conglomerate and sandstones. "The Basin of Schlau-Kladno, east of Prague, appears along the north ridge of the Silurian strata, extending for about 35 miles east and west. At Kladno it contains two principal seams, the upper being from 10 to 20, and the lower or main seam from 20 to 40 feet thick."

Moravia, &c.—In Moravia, Silesia, and Poland, the coal-measures are associated with the carboniferous limestone; the upper Silesian coal-field is situated in Prussia, Austria, Silesia, and Russian Poland. The area of this basin is about 1700 square miles, much covered by Secondary and Tertiary strata. In the Austrian portion, at Ostrau in Moravia, there are 370 seams, of which 117 are workable, and have a thickness of about 350 feet of coal.

Lias Coal of Steyerdorf.—"At Steyerdorf, near Oravicza, on the Danube, a remarkable coal-field occurs in the Lias. There are 5 seams, from 3 to 7 feet in thickness, the coal obtained being valuable for coking and iron-smelting. Similar coals occur in the Lias at Drenkowa, and near Fünfkirchen, where there are 25 workable seams, together about 80 feet thick."

Secondary coals occur in the Triassic and Jurassic strata at various points in the Alps.

Gosau.—In the Gosau strata, belonging to the Cretaceous series, coal occurs in and is worked at various points in the alpine lands. Eocene coals occur in Dalmatia, and Miocene lignites in the Vienna basin; one seam, 10 feet thick, in Southern Moravia, covering an area of about 120 square miles. "In Bohemia, Miocene brown coal strata cover a large area, the principal basins being those of Ezer, Carlsbad, and Teplitz, together about 600 square miles, the main seam occasionally attaining a thickness of over 100 feet."

Russia.—Hitherto the coal resources of Russia have been but imperfectly known. Explorations have, however, resulted in discovering coal strata of considerable magnitude and extent. These belong to the period of the Carboniferous Limestone, and resemble the lower coals of Scotland.

In Central Russia the coal-bearing area covers about 13,000 square miles, the central basin being at Tula, south of Moscow.

In Southern Russia, between the river Donetz and the head of the Sea of Azoff, an important coal-field occurs, also in the Carboniferous limestone, covering an area of 11,000 square miles. There are 60 seams of coal, 44 of which are workable, having a total thickness of 114 feet. At Lugan and Lissitchia Balka, a thickness of 30 feet of coal is found in 900 feet of strata.

Ural Chain.—In the Ural chain coal is found in sandstone, associated with the Carboniferous limestone north of Perm, between the parallels of 57° and 60° north latitude.

Poland.—"About Bendzin and Lagorze, north of Myslowitz, an extension of the Upper Silesian coal-field covers an area of about 80 square miles, being partly overlain by Permian strata. Nine seams are known, varying from 3 to 20 feet in thickness, the aggregate of the coal being about 60 feet. This is the only district in which true coal-measures occur in European Russia."

Spain.—"Measured by the northern standard, the coal-fields of Spain are of comparatively small importance. They consist only of a few small and scattered basins, in which both Carboniferous and Secondary coals are represented. The Carboniferous Limestone is considerably developed in the Cantabrian chain along the north coast, and is associated with overlying coal-measures near Oviedo and Leon. In the Satero Valley near Sotillo, north-east of Leon, a seam, called El Carmen, whose average thickness is 60 feet, is sometimes 100 feet thick, and is said to be associated with another seam which is occasionally 180 feet thick. Another basin of importance is that of Belmez and Espiel, occupying a narrow valley in older Palæozoic strata, about 20 miles north of Cordova. The other principal localities are at Villaneuva del Rio, near Seville, and San Juan de la Abaderas in Catalonia. Coals of Neocenian age occur at Montalban, in the province of Tereiel, and lignites of Miocene age at Alcay in Valencia, and Callas in Catalonia."

Portugal.—A small tract of Lower Carboniferous strata containing anthracite occurs at San Pedro de Cova near Coimbra.[1]

American Coal-Fields.

The northern parts of America contain vast concentrated masses of coal—on a scale, indeed, corresponding to the other physical facts of that wonderful region. Nova Scotia and New Brunswick possess immense stores of coal, varying in quality—some, as that of the Albert mine, having little of the structure or appearance of coal, and being anthracitic. In several places the beds are from 10 to 40 feet thick. In the vast basin west of the Alleghany Mountains are rich deposits, anthracitic near the primary rocks, with metamorphic ridges, and bituminous coal at a distance from them. "The bituminous coal-field, embracing the western part of Pennsylvania and a part of Ohio, extends over an area of 24,000 square miles, the largest accumulation of carbonaceous matter in the world. In fact, the bituminous coal-measures can probably be traced almost continuously from Pennsylvania to the Mississippi, and even into Missouri, two hundred miles west of that river!" Coal exists on the eastern slope of the Rocky Mountains: and probably also on the western side of that great range.

[1] The foregoing general descriptions of the European coal-fields are extracted or compiled from the very lucid and able article on "Coal" by Mr. H. Bauerman, &c., in the ninth edition of the "Encyclopædia Britannica." Possibly no such *résumé* exists in any work as that prepared by Mr. Bauerman. For full details of the extra European coal-fields, consult pp. 58–61 of the "Encyclopædia."

In one instance a single seam of coal is 60 feet thick, and near the middle of the basin 65 seams have been counted. These vast coal-fields, "extending from the north-eastern counties of Pennsylvania to the northern part of Alabama, and from the great Appalachian valley westward into the interior of Ohio and Kentucky, include only a portion of the original formation, immense tracts having been destroyed or removed by denudation. Upon a moderate estimate, their superficial area amounts to 63,000 square miles, fully ten times as great an area as all the *productive* coal-fields of Britain![1]

CHAPTER XXV.

GENERAL CONSIDERATIONS RELATIVE TO THE HISTORY OF COAL.

The Origin of Coal.

In its most general sense, the term "*coal*" includes all Carbonaceous minerals used as fuel; it is, however, usually restricted to the particular varieties occurring in the older or *true* Carboniferous formations.

On the continent of Europe it is customary to consider coal as divisible into two great classes, depending upon differences of colour, viz.:—

1. *Brown coal*, corresponding to the term *Lignite* used in England and France; and
2. *Black or stone coal*, which is equivalent to the true coal, as understood in England.

Coal is undoubtedly due to the transformation of vegetable matter (mainly woody fibre) by the partial elimination of oxygen and hydrogen, giving rise to a substance richer in carbon than the original wood. The nature of the change is essentially a slow oxidation under water, or any argillaceous covering sufficient to protect the dead wood from the direct action of atmospheric air, as, in contact with the latter, vegetable mould or *humus*, and not *coal*, would be produced. The products of such decomposition vary with the length of time and the nature of the plants acted upon. In the production of anthracite, *e.g.*, the change is so great that no portion of the original plant-structure can be recognised. This, however, is a case of metamorphism analogous to the transformation of sedimentary into crystalline rocks.[2]

Coal-Producing Plants.—The flora concerned in the production

[1] Consult Macfarlane, "Coal Regions of America: their Topography, Geology, and Development," 3d edition, 1875; also Taylor's "Statistics of Coal," and "Geology of Pennsylvania," by H. D. Rogers, 4 vols., Text and Atlas, 1843.

[2] Daubrée has shown that wood may be converted into anthracite coal by exposure to the action of superheated water at a temperature of 400° C.

of coal differs with different geological periods in the same ratio, on the principle that each great epoch in the earth's history has had its own special flora and fauna. Therefore, the coal in each differs more or less according to the physical constitution of the plants, as well as the geological conditions under which they grew, were deposited, and subsequently carbonised or metamorphosed into coal; hence the chief differences in the properties and nature of the *Tertiary*, *Cretaceous*, and *Jurassic* coals, as compared with those of the Palæozoic or Carboniferous and Devonian ages. The flora and the conditions of growth and development differed; and the character of the coal-producing flora of the Carboniferous era, the aspects of its whole development during the deposition of the so-called "Coal-measures" (chiefly the upper part of the Carboniferous system), have had no representative since the close of that system.

Flora.—In the British Carboniferous rocks we know of 75 genera and 328 species. The gradual increment of species from the lowest and earliest Carboniferous beds (the calciferous sandstone of Scotland) is marked and suggestive, and shows the great advance made during the true coal-producing or upper portion of the Carboniferous series. It is doubtful if a single species out of the 328 passed to the succeeding Permian series above.

Devonian and Carboniferous Flora.—The Devonian plants in Britain number only 18 genera and 27 species, 10 genera and 16 species occurring in the *Upper Devonian*. We must, however, look to the Devonian epoch of America for a remarkable development of its flora, no less than 95 genera and 160 species being known there. That much of our Carboniferous flora was derived from the Devonian of America can scarcely be doubted; for out of the 75 British Carboniferous genera, 36 also occur in the American Devonian strata, and these are the most typical or marked in the Carboniferous of Britain.

Large as the Devonian flora of America appears to have been, however, it bears no comparison with that of the *succeeding Carboniferous group*, either in America, Britain, or Europe generally, but it is the earliest terrestrial flora known of any magnitude, and from it was derived the succeeding and richer Carboniferous flora destined to play so important a part in the history and progress of civilisation. We have no clue to the region on the American continent where the Devonian plants first appeared. The *Carboniferous* rocks of America have yielded 94 genera and nearly 700 species, or almost double our own. The European flora, including that of Britain, affords 176 genera and 1370 species.

Seven of the twelve British Devonian genera occur in America, viz., *Calamites*, *Lepidodendron*, *Psilophyton*, *Sagenaria*, *Sphænopteris*, *Stigmaria*, and *Trichomanites*. On such slender evidence it is difficult to conceive from what land our Devonian or Old Red Sandstone flora was originally derived, whether migration took place from Central Europe, or *vice versâ*. The facies is, however, American rather than European; especially is this the case with the Scotch and Irish floras, through *Psilophyton*, *Palæopteris*, and *Sagenaria*.

Comparative Value of Different Floras.—The following analysis will tend to show the values of the respective floras in Britain, and the comparative prevalence of coal in the different series, although the *number* of species does not in any way determine the value of the flora as contributing to the formation of coal:—

British Tertiary strata have yielded	167	genera and	348	species.[1]	
„ Cretaceous „ „	15	„	28	„	
„ Purbeck and Wealden	27	„	39	„	
„ Jurassic strata „	64	„	191	„	
„ Triassic „ „	9	„	12	„	
„ Permian „ „	18	„	26	„	
„ Carboniferous „	75	„	328	„	
„ Devonian „ „	18	„	27	„	

There can be little doubt that much, if not all, coal results from the decomposition and transformation of the flora *upon the site of its growth*. This is strongly evidenced by the usual occurrence of a bed of clay under the coal, containing the roots of plants. This clay represents the *root bed*, which contained the roots of the overgrowing plants, and, therefore, the *old soil*, occurring below every coal-seam. In Yorkshire, the siliceous rock, called "Ganister," occurring in similar positions, shows that the coal-plants grew upon arenaceous or sandy soils.

Conditions favourable to Coal Growth.—The conditions favourable to the production of coal seem, therefore, to have been forest growth in swampy ground, and in estuaries about the mouths of great rivers—oscillations of level governing the rate of accumulative deposition, and the pauses between depression (or stationary periods) being of sufficient duration to allow of the growth and decay of plant-life, so as to form a seam of coal. The thickness, again, would seem to have been dependent upon the time and conditions allowed by the downward land-movements, which brought in new layers of sedimentary matter through river-delta action, either marine or brackish,—the sediment thus intermittently thrown down forming, on re-elevation, the soil for fresh growth. We expect, therefore, to find coal or coaly deposits wherever strata of estuarine origin are developed in considerable mass; and this is the case all through the upper Carboniferous series, the Jurassic (as finely shown in the estuarine coals of the Inferior oolite shales and sandstones of Yorkshire), and in some foreign Cretaceous rocks. All these three are coal-bearing horizons, but in very unequal degrees, abnormality being the condition of the two latter, as compared with the highly developed and true coal-measures of the Carboniferous period, or coal-measures proper. The Palæozoic coal-measures are mainly confined to countries north of the equator, especially those of the American and European continents.[2] Mesozoic coals are more abundant in the Southern Hemisphere;

[1] Both genera and species will be increased from this horizon chiefly through research in the middle Eocene strata.

[2] The vast and depressed area of the Pacific—if we argue from the presence of the carboniferous rocks of Australia, &c.—may contain regions of Palæozoic strata, and amongst them greatly extended carboniferous rocks. The older rocks of New Zealand, Van Diemen's Land, New South Wales, and Australia, clearly show how extended they must be in the South and Indo-Pacific regions.

while coals of the Tertiary Period—chiefly Lignites—seem to be almost universal, or distributed irrespective of latitude.

We have no parallel at the present day to the formation of coal as developed during the Carboniferous Epoch. That the seams of coal were accumulated over areas which were intermittent as regards terrestrial movements, there is little doubt. The earlier coal growths flourished either under salt or fresh water conditions, and the purely terrestrial coal deposits were, nevertheless, always associated with water in some form. We have proof of marine conditions from the association of marine shells and fish, &c. Thus the Coalbrookdale coal-field was undoubtedly accumulated throughout the whole of its history and growth under marine conditions, all the organic remains being marine.[1] Every coal-seam represents the accumulated plant-growth of a given period or length of time, limited either by the intermittent subsidence that governed the whole area of the coal-field, or by the interference with growth of some slowly acting cause tending to carbonisation. The Welsh coal-field alone shows a succession of coal-seams, each of which, like other entire areas, represents a former land-surface on which the vegetation flourished. This went on through a vertical thickness of 10,000 or 12,000 feet. There can, therefore, be no doubt that the coal strata of this field must have been laid down during a vast period of depression or continued subsidence. Each seam is a measure of the time of rest, which necessarily was sufficiently long to allow of the growth and decay of those plants, destined to be the future coal-seam. We must also assume that, at the close of the maximum of depression of the coal-bearing area, upward movements took place to bring the many old land-surfaces once more within the limits of life, and render them accessible also. This would involve, in the case of the Welsh coal-field, terrestrial movements to the amount of 20,000 feet in the double oscillation (*i.e.*, the downward and upward action). Should the rate of subsidence, however, have been equalled by sedimentation, or the downward movement not have been continuous, then the assumption of intermittent oscillation may not be necessary. In such cases the accumulation of the coal-seam was probably due to pauses long enough to allow for the silting up and spread of swampy plant-bearing jungles.

Flora of the Carboniferous Epoch.

The Carboniferous Epoch is sometimes called the age of plants, or period of gigantic vegetation. Doubtless, of their kind, and, on the whole, as compared with the cryptogamous flora of the present day, the tree-like forms were large and luxuriant. If the term "gigantic" be applied to the universal distribution over the globe of the same genera and species, it may, indeed, well be used in that sense; for we now know that nearly four-fifths of the Carboniferous flora were common to America and Europe, especially Nova Scotia; hence the probability of a former extension of land either continental, or

[1] Prestwich, Trans. Geol. Soc.

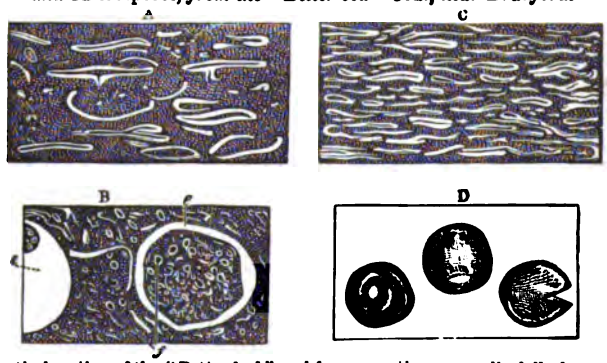
as a chain of islands now covered by the Atlantic. Many of the same genera and species range through Europe and America from the Arctic regions to 30° of latitude, or over a space occupying about 45° of latitude, and lived on through time sufficiently long to be associated vertically with 10,000 and 12,000 feet of strata. Similarity of mechanical deposits is also confirmatory of like conditions. This, added to the agreement of the Nova Scotia fossil plants and invertebrate forms of life with the Scotch fauna and flora, is at least suggestive, and points to the original connection of the two continents through land surfaces, estuarine and other conditions. Palæophytology, or the study of fossil botany, has greatly added to our knowledge of the physical state of the earth at this particular age, and its climate at different epochs; and we are, perhaps, as intimately acquainted with the nature and history of this Palæozoic flora as with many portions of the living vegetation in certain regions of the globe. No less than 75 genera of fossil plants are known in our British carboniferous rocks alone, yet only a fragment of the plants of the coal period is left to us. Brongniart recognised three periods of vegetation in the extended history of the globe, which he termed Ages, characterised by the predominance of certain distinctive or dominant forms of plants. Thus the flora of the Primary or Palæozoic Period is termed the "Reign or Age of Acrogens," so called from a great group of cellular and vascular cryptogamous plants, which greatly predominated during the early period of the earth's history, now illustrated by the Ferns, Equisetaceæ, and Lycopodiaceæ. These groups were arborescent in their habit, and of gigantic proportions. Ferns greatly predominated during this period; some 20 fossil genera are recognised in Britain. The great tree-ferns of to-day were shadowed forth by gigantic forms distributed through the coal-measures. They appear to be the only carboniferous fossil group having any reliable relationship to those now living.[1] The lycopodiaceæ, chiefly met with in our coal-measures, are Lepidodendron (its fruit, Lepidostrobus), Ulodendron, Knorria, Bothrodendron, &c., and, most abundant and important of all, the genus Sigillaria,[2] and its roots Stigmaria, which ramify through almost every underclay in all our coal-fields, and every coal-field in the world. Amongst the ferns, the most typical and common are Neuropteris, Pecopteris, Odontopteris, Alethopteris, Adiantites, and Sphænopteris, &c., which occur in the shales of the roof of many coal-seams, and in argillaceous iron nodules below and above the coal. The equisetaceæ, common fossils under the name of Calamites (and the rarer Volkmannia), abound from top to bottom of the coal-measures. They are gigantic, fluted, reed-like plants. The acicular, strap, and wedge-shaped bodies in almost every shale roof, called Sphenophyllum, Asterophyllites, and Annularia, probably were the

[1] They are referred to the fossil genus Caulopteris. Psaronius was probably a tree fern.

[2] Many occur as lofty trees, 40 to 60 feet in height, with a diameter of 4 to 5 feet. Many still stand erect in our coal-measures, passing through shales, sandstones, and clay, which accumulated around them when living.

foliage of the genus Calamites. These, and many other great plants of the coal period, grew in dense masses over low-lying lands or regions, chiefly perhaps the deltas of large rivers or estuaries slightly elevated above the sea level, and liable to submergence on slow periodical oscillations of the land. Associated marine remains and occasionally fresh-water forms occur; and enormous thickness of strata of sandstone and shale, to which the coal is subordinate, fully attest the mode and site of accumulation, and clearly demonstrate that the vegetation or flora grew on the spot where it became fossilised, and is now coal. Again, its microscopic structure, combustible properties, and position in the strata, demonstrate its vegetable origin, and a uniformity in the vegetation of the coal period, which has now no parallel (see fig.)

Microscopical Section of Coal, showing the Mode of Occurrence of the Macrospores *and* Microspores, *from the "Better-bed" Coal, near Bradford.*



A. Vertical section of the "Better-bed" coal from a portion unusually full of *sporangia*.
B. Section of same coal parallel to bedding showing sporangia (*e*), containing *spores* (*f*), which under the microscope appear as bright yellow rings enclosing the spores.
C. "White coal," Australian. Transverse section showing compressed sporangia.
D. Sporangia or *macrospores* separated from the moss. The *microspores* are contained in the hollow sac.
"The Better-bed" coal of Low Moor is largely composed of these *macrospores*, and the recent white coal of Australia also.

Structure of Coal.—The peculiarity of the flora, or special conditions of carbonisation and subsequent metamorphism, give us new elements of difference or variety, rendering one seam of greater value than another for economical purposes. Hence it is that, in the same coal-field, we have superimposed, one upon the other, coals of different virtue, power, and uses,—one suitable for the production of gas, or gas coal; another for the more rapid production of steam, or steam coals; another adapted for the smelting of iron, or furnace coals; others oil-producers; some smokeless and pure in carbon; others, again, for domestic purposes, and some at present useless.[1] Experience,

[1] The peculiarities of a particular coal in Yorkshire, the "Better-bed" at Bradford, and another from the Moira area, are examples of structure and contents. These coals are largely made up of sporangia and spores, shed from the cones of Lepidostrobi, and constituting a large mass of the deposit. Professors Morris and Fleming had, many years since, noticed the same bodies in other coals,

through trial alone, has hitherto guided us to a knowledge of these various properties. What might be done under strict chemical analysis for the adaptability and use of special coals, we ought now to show by turning our utmost attention to the intrinsic use, power, and capability of *every workable and rejected seam*, for the time will come, and that shortly, when science only will enable us to save and economise our coal.

What are we to say of *time*, so important an element, and one of the chief agents concerned in the production of our coal? Where is our standard by which to estimate the growth and decay of these ancient forests? We have none, neither can we approximate it. The great Welsh coal-field, before alluded to, with its 10,000 or 12,000 feet of accumulated strata, its carbonised plants, and all their history and development, *is a measure of time;* and the vertical displacement which the whole coal-field underwent in one geological period sufficient to bring the present summit of the Alps to the level of the sea—14,000 feet—*is another measure;* but by what given quantity or standard can we estimate these long-continued, slow, and certain operations governed by natural laws?

Coal under the Newer Rocks, or Concealed Coal-Fields.

The questions of the extension of our coal-fields, and the limit in depth to which coal-mining can be safely, economically, and profitably carried down, or, in other words, the physical limits to deep mining, have long engaged serious attention.

Exposed and Concealed Fields.—We have both *exposed* and *concealed* coal-fields throughout certain parts of England, the term *exposed*, or visible, being applied to those tracts where the coal-measures are seen at the surface without any superincumbent and newer sedimentary strata covering them. This may be attributed to two causes—first, elevation from below, through forces acting from within; or, secondly, the removal of overlying strata through denudation, so as to expose the older, or those on which they rest, these latter being the concealed series. The great South Wales field and the Forest of Dean are fair examples of *exposed* or visible coal-fields; the Somersetshire, part of the Leicestershire, and eastern part of the Northumberland and Durham under the sea, the area between the Warwickshire and South Staffordshire coal-fields, Cheshire, and the Severn Valley, &c., are examples of *concealed fields*. The Permian and Triassic Red Rocks overlie or cover up these concealed reservoirs. Our knowledge of the extent of these subterranean resources has of late years considerably advanced, owing to more exact research into the physical geology of

English and Scotch. Principal Dawson, of Montreal, has examined 80 coal-seams in Nova Scotia. He recognised these bodies in 16 seams. The "white coal" of Australia is entirely composed of similar bodies. Sir C. Lyell has figured these macrospores and microspores in his "Student's Geology," p. 405. They are reproduced in the above figure.

the British Islands, and this chiefly through the labours of the Geological Survey, and the works of Professor Hull, F.R.S. For the clear understanding and solution of this problem, it is necessary to know and to restore the original limits or margin of the carboniferous rocks at the time of deposition, and also the directions of the axes of disturbance (upheaval or depression) along which the subsequent terrestrial movements have taken place, and also the amount of denudation the overlying and also *now* concealed rocks may have undergone. The researches of the Geological Survey have afforded most of the necessary detail for the consideration of this complex problem.

Investigation shows that extensive tracts of coal exist under the Permian and New Red Sandstone, and that in some places other superincumbent strata occur, in districts hitherto unknown or unproved. The calculated area of concealed coal-fields is 2947 square miles, and the quantity of coal within this area, down to the allowed *and prescribed depth of* 4000 *feet* (as limit of working), is 56,273 million tons, 40 per cent. being allowed for loss, waste, and contingencies. The quantity of coal beneath the same rocks at depths *exceeding* 4000 *feet*, and occupying 843 square miles, is computed to be 41,144 million tons; of this quantity about 29,000 million tons are assumed to lie at depths between 4000 and 6000 feet.[1] The remainder, over 15,000 million tons, is assumed to lie at depths between 6000 feet and 10,000 feet, at which depth the temperature would be 215° Fahr., or 3° above boiling point. To the above are to be added 7320 million tons as being at greater depths than 4000 feet, *within the areas of known coal-fields.* This gives us a total quantity of coal lying at depths exceeding 4000 feet of 48,465 million tons. It is a matter of conjecture whether this coal, or any portion of it, can ever be worked; if not, it is lost to use.[2] Large as these items and amounts may appear to those who have not looked into the question, they are, nevertheless, not over-calculated, and the estimates have been prepared with scrupulous care.

Estimated Quantity of Available Coal in the British Islands.

We must refer those who would examine this question in detail to the volume of the Royal Commission on Coal, where every item is stated and the results tabulated. Of necessity we are obliged to make use of these statistics to illustrate the history of coal as associated with its geology.

Adopting, then, the limit of 4000 feet as the practical working depth, we have, in *our visible* coal-fields, available coal to the extent

[1] At 6000 feet the temperature of the earth would exceed 150° Fahr.—fatal to life with our present appliances.

[2] At present, in England, no workings exceed 2500 feet. Professor W. W. Smyth, from a communication from Professor Trosenter, of Liége, states that at Hainault (Belgium) coal is being worked at the depth of 2800 feet, and that one pit has been sunk 3411 feet.

of 90,207 million tons. This great amount is derived from the 17 coal-fields in England, 16 in Scotland, and 6 in Ireland; or—

England	80,207,939,468 tons.
Scotland	9,843,455,930 „
Ireland	155,680,000 „

Quantity of Concealed Coal.—The *concealed coal-measures* or coal-fields contain, to the same depth, 56,273 million tons, making a total of 146,480 million tons of available coal. From this total we deduct, for seams under 2 feet in thickness, 1–20th, or 7324 millions; thus leaving for future use 139,156 million tons of fuel. The demand or yield is now nearly 130 million tons per annum. At this rate of consumption we have coal enough to last us over 1070 years.

Duration.—This brings us to the consideration of the *probable duration of our coal*—a momentous question for England and the future prosperity of her people. It has occupied the minds of physicists, mathematicians, statisticians, and statesmen. The Royal Commission dealt largely with this question in all its bearings—viz., waste of fuel by bad working and combustion, manufactures, economy, population, &c. Doubtless the question of the exhaustibility of our coal-fields is a highly complicated one, the whole turning upon consumption, supply and demand, and time. We have so much supply, and no more. Largely are we now drawing upon our reserves. Yearly 130 millions of tons are withdrawn. None is returned or capitalised. No reproduction takes place, for "coal is no longer forming; and be it remembered that we are exhausting about 20 square miles of fuel every year, and working away 5 acres of coal, 2 feet thick, every hour, night and day, or 1¼ acre every quarter of an hour." This in the face of no substitute, no reproduction. "We are drawing more and more upon a capital which yields no annual interest, but—once converted to light, and heat, and force—is gone into space for ever."[1] The greatest branches of British industry requiring a constant and immediate suitable supply of coal, and that of a special chemical nature, are gas-making, iron-smelting, and manufacturing. To these must be added the demand for marine purposes. For gas-making alone nearly 5 million tons are consumed annually in Britain. It may be asked, how much for the production of steam power, the smelting of ores, locomotion by sea and land, the lighting of cities, and warming of houses? Fuel is as "necessary to social life as food to man," and yet we are lavish, if not wasteful, in its use.

These stores were laid down, atom by atom, in the working of natural laws and causes, and took countless ages in preparation; and we, as a people, fortunately occupy one of those rich areas on the earth's surface which hold this priceless gift from nature. At the commencement of this century the quantity of coal raised did not exceed 10 millions of tons; it is now 130 millions, and in all directions there is still an augmenting demand upon our resources. The increase of

[1] On the Coal Question (Jevons).

population alone is an item both insinuating and certain. It is estimated by some that in ten years hence our extraction may be over 150 millions of tons per year, thus nearly trebling the output in twenty years. We have become the coal granary, the reserve, the working or producing coal-field for much of the world; and out of the 200 millions of tons supposed to be extracted yearly from all the coal-fields of the globe, we are now raising 130 millions, or considerably more than one-half.

Physical Limits to Deep Coal-Mining.

It is well known that many portions of our coal-fields lie at greater depths than have yet been reached in mining, or through any other mode of testing the vertical capabilities of their resources. This is the case with the centre of the Bristol coal-field, both north and south; and many others, especially those covered up by newer formations, such as the Permian, Triassic, and, in places, the Jurassic Rocks. Again, those coal-fields which have extensive areas, and are not much disturbed by faults or movements along either their major or minor axes, are frequently deep, deeper than the 3000 feet to which modern appliances have enabled us profitably to penetrate. This important question in the future history of our coal supply, as to the possibility of working profitably to a greater depth, has received much attention. The result has been highly favourable, so far as quantity is concerned. It has been shown that in the British coal-fields *below* the calculated maximum depth at which it was considered safe to estimate for, we have reserves to the extent of over 48,000 millions of tons; this quantity ranging between 4000 and 6000 feet in depth. We believe that 4000 feet may be reached and worked with safety.[1] The two agencies which operate with the greatest energy and certainty as we descend vertically from the surface are "temperature and pressure," and they are the chief obstacles which, with present appliances, now limit the practicable depth of working our coal.

In other words, increase of temperature, which accompanies increase of depth, is the chief natural limiting cause. At 2500 feet the mean temperature reaches 90°, about tropical heat, which, unless considerably ventilated and reduced by artificial means, is a source of waste of human power and energy. The workable depth of coal-mines depends upon human endurance of high temperature, and the possi bility of reducing the temperature of the air in contact with heated strata. Labour is not practicable in moist air at the temperature of the blood, or 98°; at 3000 feet the temperature equals this, which, added to the humid condition of the air along the working faces of the coal, renders labour irksome and dangerous. It is found that under the "long-wall system of working, a difference of temperature, amounting to 7°, exists between the temperature of the air and the

[1] Mr. W. W. Smyth is of opinion, from recent experience in deep mines, that the difficulty of temperature may, by due appliances, be overcome to even a greater depth than 4000 feet.

coal-face; hence by this system we gain 400 feet in depth for the same temperature of 98°, or at a depth of 3400 feet under the long-wall system the temperature is the same as that at 3000 feet with the cellular, or pillar, or post-and-stall system."[1] The rate of increase of temperature in our coal-mines is 1° Fahr. for every 60 feet in depth. At the Rose Bridge coal-pit, near Wigan, the shaft is nearly 2500 feet deep; down to 1800 feet the ratio of 1° per 60 feet held good; it then became more rapid, and at 2376 feet the thermometer stood at 92° Fahr. It thus appears that, at the depth of 3420 feet, the temperature of the air would equal that of the blood. Beyond this temperature, no matter at what depth, labour would be almost impossible, especially so in moist air.[2]

The influence of pressure is more difficult to realise; but in coal-mining, as distinguished from the working of "mineral veins," it must seriously operate, owing to its force being always vertical, and existing over a plane either horizontal or inclined, and usually of great extent. The accumulative weight of 3000 or 4000 feet of dense strata per square yard, or mile, upon some coals, or their roof, or the softer underclays and roadways, &c., underground, is enormous, and difficult to deal with; increased density of the coal-seams themselves does not seem to be recognised or manifested. Cost is another element that may operate against winning deep coals; the fact of two shafts having to be constructed, *no matter to what depth*, is one amongst many serious items; the increased cost of working, winding, wear and tear of machinery and materials, presents another obstacle, and the deeper the pits, of course, the larger the united and greater all the subsequent expenses; for, if it cost £100,000 to win coals at 2000 feet, 4000 feet would probably cost £300,000, and this before a ton of coal would be brought to bank. Few, *even now*, will attempt to win coal at such proportionate cost and risk. Again, the outlay of capital involved in winning coal at great depths renders it necessary to possess and work large areas for each sinking, and, consequently, air-courses of great length. Nevertheless, momentous results depend upon a constant supply of coal in Britain, for our commercial prosperity is founded upon its possession and use.

[1] Hull, *loc. cit.*, p. 435.

[2] In the copper "United Mines," St. Day's, Cornwall, the temperature at the bottom, in the Hot-Lode workings, is 114°, 117°, 120°. The men work fifteen minutes at a time, or three hours daily.

CHAPTER XXVI.

PALÆONTOLOGY OF THE CARBONIFEROUS ROCKS.

Plantæ.—Large as the Devonian flora of America appears to have been, it bears no comparison with the succeeding Carboniferous group either in America, Britain, or Europe generally. Ninety-five genera and about 320 species constitute the whole of the known Devonian Plantæ, through their entire distribution. That much of the Carboniferous flora was derived from the Devonian is evident. Of the 75 British genera, 36 occurred in the Devonian of America, and these are also the most typical or marked in the Carboniferous system.[1]

The American Carboniferous flora, according to the published lists, &c., numbers 94 genêra and 695 species; and the European flora, including the British, 176 genera and 1370 species; those occurring in the 8 divisions of our Carboniferous strata number 328, illustrating 75 genera. Their stratigraphical distribution through the following 8 series or groups of strata is as follows:—

Calciferous sandstone . . .	10 genera	and 12 species.
Lower limestone shale . . .	22 „	44 „
Carboniferous limestone . . .	13 „	22 „
Yoredale rocks	none „	none „
Millstone grit	10 „	27 „
Lower coal-measures	54 „	211 „
Middle „	34 „	128 „
Upper „	33 „	168 „

Ten genera are largely represented in Britain, and contain 192 species out of the known 328: they are *Alethopteris* 10 species, *Asterophyllites* 12, *Calamites* 12, *Lepidodendron* 22, *Lepidostrobus* 8 (probably we may never know to what species of *Lepidodendra* all these *Lepidostrobi* belong), *Neuropteris* 23, *Pecopteris* 29, *Sigillaria* 31, *Sphenopteris* 34, *Ulodendron* 11. All the *Alethopteri* are from the Coal-measures. The *Asterophyllites*, with two exceptions (*A. foliosus* and *A. longifolia*), are also Coal-measure fossils. The *Calamites* range from the Calciferous sandstone to the Upper Coal-measures. *Neuropteris cordata*, *N. flexuosa*, and *N. gigantea*, occur in the Millstone Grit; the *Pecopteri* are essentially Upper Carboniferous. Regarding the distribution in time of the Carboniferous flora, we know that many species occurring in Pennsylvania and Nova Scotia are identical with European and British forms. This indicates a greater similarity and equality of climate than now prevails, and also, as pointed out, the

[1] We owe our chief knowledge of the Devonian and Carboniferous flora of North America to the researches of Dr. Dawson of Montreal, Vanuxem, Hartt, Rogers, Lesquereux, and Newberry, who have all largely added to the literature of the fossil flora of the American Continent.

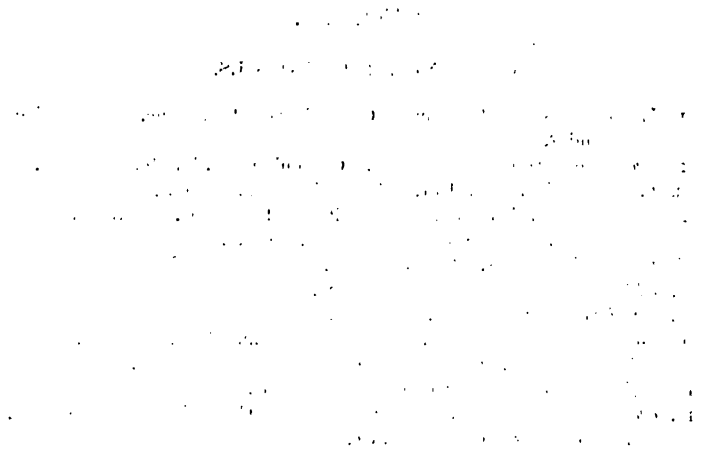


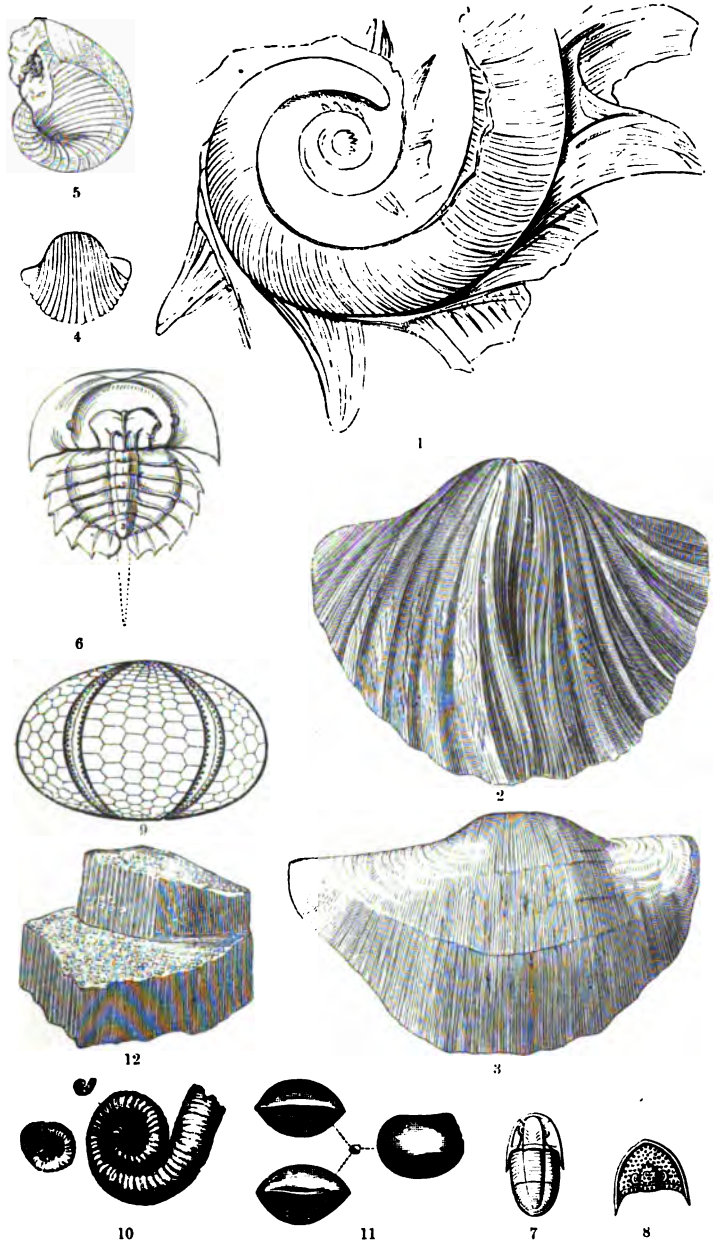
PLATE XII.

CARBONIFEROUS FOSSILS.

1. *Phanerotinus cristatus* (Sow.) Carboniferous Limestone. Derbyshire, Ireland, &c.
2. *Productus giganteus* (Mart.) var. Carboniferous Limestone—*passim*.
3. *Productus giganteus* (Mart.) Carboniferous Limestone.
4. *Bellerophon Urei* (Flemg.) Carboniferous Limestone. Rutherglen.
5. *Do.* *hiulcus* (Sow.) Derbyshire, &c., &c.
6. *Prestrichia anthrax.* Coal-measures. Coalbrook Dale.
7. *Phillipsia.* Carboniferous Limestone.
8. *Brachymetopus ouralicus?* Derbyshire.
9. *Palæchinus gigas* (M'Coy). Carboniferous Limestone. Ireland.
10. *Spirorbis carbonarius* (Murch.) Carboniferous Limestone.
11. *Leperditia inflata.* Carboniferous Limestone.
12. *Chætetes* (*Alveolites*) *depressus* (Flemg.) Carboniferous Limestone. Bristol, Yorkshire, Ireland, &c.

PLATE XII.

CARBONIFEROUS FOSSILS.



possible connection of the coal-bearing areas of Europe with those of America, either by continuous land or by groups of islands.

Protozoa: Spongida.—Eight genera and 14 species are confined to the Carboniferous limestone and shales below. The 3 British species, *Palæacis cuneiformis*, *P. cyclostoma*, and *P. obtusa*, have a wide geographical range, being most widely distributed; but none of the 8 genera and 14 species appear to have ranged above the Carboniferous limestone in any area.

Protozoa: Foraminifera.—Fifteen genera (11 belonging to the Imperforata and 4 to the Perforata) with 43 species range through the lower portion of the Carboniferous group; 40 of the 43 species occur in the Carboniferous limestone.[1]

Hydrozoa.—*Arbusculites argenteus*, *Palæocoryne radiata*, and *P. Scotica* are the only known genera in this class. All are from the Carboniferous limestone.

Actinozoa.—Both the Rugosa and Tabulata are well represented in the Carboniferous rocks, especially the former. Twenty-one genera fall under that order, and 14 in the Tabulata. *Cladochonus* (*Jania*) and *Aulopora* are the only representatives of the Tubulosa. *Aulopora*, which is probably the young state of *Syringopora*, usually referred to the Tubulosa, must be placed with the Alcyonaria. Nine families, 39 genera, and 145 species constitute the Carboniferous Cœlenterate fauna, The two families of numerical value are the Favositidæ, with 5 genera, and Cyathophyllidæ, with 20. No species of coral is known *above* the Yoredale rocks, and only 2 genera and 2 species occur in that series, viz., *Favosites tumidus* and *Zaphrentis Phillipsii*. The Calciferous sandstones yield 3 species, *Alveolites septosus*, *Favosites tumidus*, and *Lithostrotion junceum*.

The Lower Limestone Shales yield 13 genera and 30 species; the nature of the deposit greatly influenced and determined the presence of species. Nearly all the corals in the shales are simple forms, and dwarfed in habit, certainly more so than those species that lived in clearer and deeper water, where flourished most of the compound forms which occur so abundantly in the limestone beds above.[2] This difference, under petrological association, is manifest on carefully examining the stratigraphical position of the corals in many localities. The limestone is coralliferous throughout, and the fullest evidence may be obtained of large and extensive reefs composed essentially or mainly of the Rugosa, *Lithostrotion*, *Lonsdaleia*, forms of *Cyathophyllum*, and numerous other species. The Carboniferous limestone of the British Islands yields nearly every known genus and species; 36 genera and 141 species are found in this limestone in one locality or other in Great Britain and Ireland.

[1] See Brady, Brit. Carboniferous and Permian Foraminifera (Palæontographical Soc.), 1876.

[2] These shales in their normal condition and development are confined to the West of England (the Bristol area and South Wales), and are about 500 feet in thickness. They occur between the base of the Carboniferous limestone and the top of the Old Red Sandstone.

The whole class culminates here, only 2 genera passing to the Yoredale beds (*Favosites tumidus* and *Zaphrentis Phillipsii*). This termination in time of the Actinozoa was undoubtedly due to those physical changes which took place in consequence of the elevation of the sea-bed prior to the deposition of the Permian strata. The accompanying table shows the geographical distribution in Britain and Belgium of 19 of the chief British genera, and, still further, their correlation with America.

TABLE XXX.—*Showing the Numerical Value of the Species in the chief Genera of Actinozoa in Great Britain, Belgium, and America.*

	England.	Scotland	Ireland.	Belgium.	America.
Amplexus	6	4	4	12	5
Aulophyllum	2	2	2	...	...
Chætetes	4	2	4	2	3
Cladochonus	4	...	2	2	...
Clisiophyllum	4	5	4	3	...
Cyathaxonia	2	1	...	3	6
Cyathophyllum	10	5	6	7	3
Cyclophyllum	2	2	1	...	...
Favosites	5	1	3	5	3
Heterophyllia	2	6	...	...	...
Lithostrotion	16	10	12	4	5
Lonsdaleia	4	2	...	1	1
Michelinia	4	2	5	4	1
Palæacis	1	2	...	2	...
Phillipsastræa	2	...	...	...	...
Syringopora	5	3	6	5	4
Zaphrentis	8	10	5	21	18
	81	57	54	71	49

Echinodermata.—The class Echinodermata is represented in the Carboniferous rocks by 5 orders—the Crinoidea, the Blastoidea, the Perischoechinoidea, the Echinoidea, and the Holothuroidea, through the occurrence of Synaptæ. Twenty-seven genera and 139 species constitute the entire fauna, and the whole are in the Carboniferous limestone division.

The Lower Limestone Shales yield 31 species, illustrating the genera *Actinocrinus*, *Archæocidaris*, *Astrocrinus*, *Atocrinus*, *Cyathocrinus*, *Palæchinus*, *Platycrinus*, *Poteriocrinus*, *Rhodocrinus*, *Taxocrinus*, and *Dichocrinus*.

The characteristic genera, and those containing the largest number of species, are—*Actinocrinus*, *Cyathocrinus*, *Platycrinus*, and *Rhodocrinus*. The order Blastoidea, through the Pentremitidæ, 16 species, are all confined to the Carboniferous limestone proper. The singular genera *Palæchinus*, *Perischodomus*, and *Melonites*, are essentially characteristic, and largely predominate in the Carboniferous rocks of America.

Annelida.—Thirty-four species of this class, belonging to 11 genera, wander through the 8 divisions. *Spirorbis* numbers 14 species, and *Serpula* 7; the remaining genera have only 1 or 2 species each. *Serpulites carbonarius*, *Spirorbis pusillus*, *S. caperatus*, and *S. helicteres* are the only 4 species that range above the Carboniferous limestone and into the Coal-measures, where the argillaceous shales and clays are of marine or estuarine origin. The Calciferous sandstones of Scotland have yielded *Serpulites pusillus*, *S. carbonarius*, *Spirorbis Eichwaldi*, *S. globosus*, and *S. helicteres*.[1]

Crustacea.—The Carboniferous rocks in Britain yield 38 genera and 173 species, representing the Ostracoda, Phyllopoda, Merostomata, Pœcilopoda, Stomapoda, Macrura, and Trilobita. The latter are illustrated by the 3 genera, *Brachymetopus*, *Griffithides*, and *Phillipsia*, 16 species. This group entirely disappears with the close of the Carboniferous rocks, no species being known above the limestone.

The Calciferous Sandstone (Tuedian) has yielded 9 genera and 15 species, mostly Ostracoda; the Macrura, through *Anthrapalæmon*, first appear in the Tuedian group, 3 other species of the same genus occur in the Coal-measures.

Lower Limestone Shales.—Seventeen genera and 48 species, chiefly Ostracoda and Phyllopoda, are individually abundant in the shales below the great limestone.

Carboniferous Limestone.—One hundred and fifty-nine species are recognised and described from the Carboniferous limestone proper, illustrating 28 genera out of 33. Those genera wanting in the limestone are *Anthrapalæmon*, *Belinurus*, *Pygocephalus*, and *Candona*. The Ostracoda number no less than 15 genera and 107 species; the Phyllopoda 8 genera and 36 species; the Trilobita 3, if not 4, genera and 16 species.

Millstone Grit.—No Crustacean remains known.

Lower Coal-Measures.—Ostracoda, with 13 species—Phyllopoda 8, Pœcilopoda 4, with 3 species of *Anthrapalæmon*, two of which first appeared in the Calciferous sandstone, *A. Maconochii* and *A. Woodwardii*. *A. dubius*, *A. Grossarti*, and *A. Russelianus* belong to the Lower and Upper Coal-measures. This ancient type has been found in the Coal-measures of both Europe and North America. *Anthrapalæmon* is related to the living *Galathea*. Of the suborder Xiphosura or Pœcilopoda we possess 2 genera, *Belinurus* and *Prestwichia*, this last allied to *Neolimulus* of the Upper Silurian. The Pennystones of Coalbrook Dale yield *Prestwichia* (*Limulus*) *rotundata*. *Pygocephalus Cooperi* and *P. Huxleyi* occur in the Lower Coal-measures. These Podophthalmatous Stomapods, with the Decapod *Anthrapalæmon*, carry back in time this order of the Crustacea.

Middle Coal-Measures.—All the known Crustacea in the Middle Coal-measures are *Anthrapalæmon dubius*, *Belinurus bellulus*, *Beyrichia arcuata*, *B. Binneyana*, *Estheria Beinertiana*, and *E. striata*.

Upper Coal-Measures.—Ten genera and 16 species compose the

[1] See Paper by R. Etheridge, jun., Geol. Mag., vol. vii., Decade II. 1880.

Crustacean fauna of this horizon—Ostracoda 7, Phyllopoda 7, Pœcilopoda 1, and the Decapod *Anthrapalæmon Grossarti.*

Polyzoa.—The Carboniferous Polyzoa as a group constitute by far the largest series in any division of the Palæozoic rocks. Seventy-eight species range through the three lower horizons of the Carboniferous series, 64 belonging to the true Carboniferous Limestone, 28 to the Lower Limestone Shales, and 4 to the Calciferous series; not a single species passes to or occurs in the Yoredale, Millstone Grit, or either one of the three divisions of the Coal-measures. The whole group essentially belongs to the Calcareous rocks and shales at the base of the formation; the large genera are—*Ceriopora, Fenestella, Glauconome* (*Acanthocladia*), and *Polypora.* Twenty other genera of zoological value occur, but the species are few in each genus (1 to 4). *Actinostoma, Carinella, Diastopora, Goniocladia, Hemitrypa, Ptilopora, Rhabdomeson, Synocladia,* and *Vincularia* are the chief genera. None of the Palæozoic genera lived on or extended into the Mesozoic period, and the Fenestellæ become extinct in the Permian rocks.

Calciferous Sandstone.—Archæopora nexilis, Ceriopora similis, Fenestella Morrisii, F. plebeia, F. tuberculato-carinata, and *Glauconome gracilis* appear to be all that are known in these lowest beds of the northern Carboniferous rocks.

Lower Limestone Shales.—Thirteen genera and 28 species illustrate these shaly beds. The three chief genera are—*Fenestella, Glauconome,* and *Pustulipora;* the remaining genera have only 1 species each.

Carboniferous Limestone.—Sixty-four species occur, belonging to 19 genera. The most important are—*Fenestella* with 25 species, *Glauconome* 8, *Polypora* 8, *Rhabdomeson* 3, *Pustulipora* 2, and *Ceriopora* 5; these, although poor in species, are highly characteristic. Amongst 13 remaining genera may be named *Sulcoretepora, Synocladia, Vincularia, Actinostoma,* and *Diastopora.* No species passes to higher strata, or above the Carboniferous limestone.

Arachnida.—The Arachnida have only been detected in the Lower Coal-measures.* We have 4 species representing 3 genera—*Architarbus subovalis, Eophrynus Prestvicii, Eoscorpius anglius,* and *E. carbonarius. E. carbonarius* and *Architarbus* are also American species, occurring in the Coal-measures of Illinois. The occurrence of two of the three genera in two areas so widely separated is significant, with many other facts, of the probability of the continuity of land between Britain and America during the long period required for the deposition of the Coal-measures and the accumulation of coal.

Myriapoda.—The 2 genera of Chilognathous Myriapoda, *Euphoberia* and *Xylobius,* which occur in our Coal-measures, are also American; this fact, together with the occurrence of the Arachnida, is strong presumptive evidence of continuity of land, densely covered with the peculiar flora known to have flourished during the Coal-measure period. We possess 3 species of *Euphoberia*—viz., *E. anthrax,* Salt., *E. Brownii,* and *E. ferox.* Dr. Dawson's genus *Xylobius,* as well as

PLATE XIII.

CARBONIFEROUS FOSSILS.

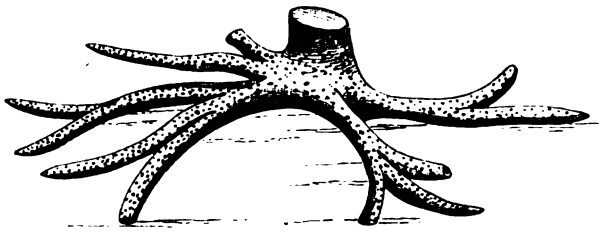
1. *Stigmaria ficoides* (Brong.) Root of Sigillaria. Common in every coalfield. Worldwide.
2. *Lithostrotion basaltiforme* (Edw.) *L. striatum* (Fleng.) Carboniferous Limestone. Everywhere.

2*a*. Enlarged section of calice of single corallite.

3. *Clisiophyllum turbinatum* (M'Coy). Carboniferous Limestone. Scotland, Derbyshire, &c.
4. *Aviculopecten papyraceus* (Goldf.) Carboniferous (coal-measures). Yorkshire, Lancashire, &c.
5. *Conocardium minax* (Phill.) Carboniferous Limestone. Lancashire, Ireland, Yorkshire.
6. *Conocardium aliforme* (Sow.) Carboniferous Limestone. Lancashire, Isle of Man, Ireland.
7. *Goniatites Listeri* (Martin). Carboniferous Limestone. Yorkshire, Lancashire.
8. *Goniatites sphæroidalis* (M'Coy). Carboniferous Limestone. Ireland.
9. *Nautilus sulcatus* (Sow.) Carboniferous Limestone. Shropshire, Ireland, &c.

PLATE XIII.

CARBONIFEROUS FOSSILS.



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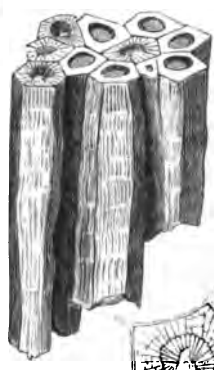

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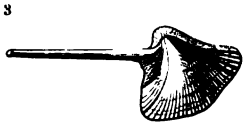

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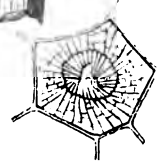

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the known American species "*Sigillariæ*," lends additional interest to the attempt to correlate the fauna and flora of our Coal-measures with those of the American continent; for many species of plants are identical, and with them associated faunal groups.

Insecta.—Both the Orthoptera and Coleoptera are represented in our Coal-measures. The Mantidæ through the genus *Lithomantis*, the Locustidæ through *Gryllacris;* these two genera belong to the Orthoptera.[1] These all occur in our Lower Coal-measures.

Every fresh investigation into the rocks that hold the extinct flora of our coal-fields will bring to light the remains of the three last groups, the Arachnida, Myriopoda, and Insecta, which were intimately associated with the vegetation of the Carboniferous epoch, and, with other remains in the same rocks, show that the Atlantic Ocean covers a vast area of once continuous or contiguous land.

All who have studied the varied conditions of the Carboniferous series, the deposition of its strata, and the distribution of its fauna, will admit that its history is only to be written through the great and reliable group of the Mollusca (Brachiopoda, Pelecypoda, Gasteropoda, Pteropoda, Heteropoda, and Cephalopoda), whose 6 divisions or classes number 115 genera and 970 species, or nearly one-half the entire known Carboniferous fauna. So many of the genera have come down to the present day, that inferentially, through observation, we know their habits in Carboniferous times: they show us that, during the accumulation of the Carboniferous limestone, moderately deep-sea conditions prevailed, and the Molluscan fauna then surpassed all subsequent numerical development during the Carboniferous period. Ultimately, physical changes caused the sea to shallow, thus altering all bathymetrical conditions at the same time. Littoral species died out, through altered circumstances; and the habits of the deeper-sea fauna changed also on slow elevation, the zonal lines of life undergoing modification through adaptation. Plainly are these modifications and changes to be observed through the several changes, from the Calciferous sandstones to the summit of the Coal measures.

Every extended sea-bed has its own conditions and its own fauna; the exact nature of that sea-bottom it is difficult to predicate; it can only be learnt through examination. Admitting that the fauna of any group of rocks was as local as the physical conditions during deposition (and the maximum of life in any particular group is usually local), it will show itself in any area, in any part of an epoch or of a stage; it is governed chiefly by the nature of the sediment, by food, and by temperature. The questions of the *appearance* of species—their *duration, migration, extinction, recurrence,* and the many other conditions that govern marine life in all its phases—are to be studied through a careful investigation of the physical history of the Carboniferous rocks; and through no other zoological group do we receive so much instruction as through the Mollusca.

[1] The history and zoological affinities of these Carboniferous Insecta and Arachnida have been ably described by Dr. H. Woodward, F.R.S., in the Quart. Jour. Geol. Soc., vol. xxxii.

Brachiopoda.—Both the Tretenterata, or "Inarticulata," and the Clistenterata, or "Articulata," are largely represented in the Carboniferous rocks, many genera appearing for the first time, specially characterising the lower members of the Carboniferous group—such as *Hypodema* and *Syringothyris*, neither of which appeared in older strata.

The specific development of *Productus* has no precedent or parallel in any other group of British strata. Forty-five species occur, ranging from the Calciferous sandstone to the Lower Coal-measures inclusive, 5 species in the Calciferous series, 16 in the Lower Limestone Shale, 41 in the Carboniferous limestone, 7 in the Yoredale, 5 in the Millstone Grit, and 4 in the Coal-measures. *Productus* passes to the Permian rocks, and is there represented by *P. horridus*, its last appearance.

Spirifera attains its highest development in this horizon also; 35 species range through the Carboniferous rocks, associated with the *Producti;* their numerical value is seen in the Calciferous sandstone with 3 species, Lower Limestone Shale 17, Carboniferous limestone 30, Yoredale rocks 6, Millstone Grit 4, and the Lower Coal-measures 4. No less than 185 species (British, European, and American) have been described. The *Rhynchonellæ* of our Carboniferous rocks number 21 out of the 30 known European species; the 3 derived from the Devonian are *R. pleurodon*, *R. pugnus*, and *R. reniformis*.

The genus *Terebratula* begins here to be numerically abundant, no species being known in the Silurian strata, and the Devonian rocks yield only 4 species, whilst 7 are Carboniferous. The great development of this genus in the Jurassic rocks surpasses that of all other Clistenterata; in our own area they apparently nearly died out or migrated after the Carboniferous epoch, none occurring in the Trias.

The significance or importance of *Productus* as a Carboniferous genus cannot be overlooked when determining through its species definite horizons in these rocks. It is ubiquitous; in no region on the globe, where the Carboniferous rocks are developed, do we not find this characteristic shell in vast abundance—in the Polar regions, Australia, New Zealand, Van Diemen's Land, India, America (in 15 States), throughout Europe, and in Africa.

The British Carboniferous Brachiopoda number 19 genera and 175 species; and 7 of the 8 horizons possess them; 9 genera and 18 species occur in the Calciferous sandstones of Scotland; 11 genera and 80 species range through the thin-bedded Carboniferous limestone shales, or the *lower* limestones; 14 genera and 172 species have been collected and named from the Carboniferous limestone alone.

TABLE XXXI.—*Showing the Geographical Distribution of the chief Genera of British Carboniferous Brachiopoda. Those in Italics are the most prolific in Species.*

	England.	Scotland.	Ireland.	Belgium.	America.
Camarophoria . . .	4	1	3	1	3
Chonetes	12	10	13	5	28
Crania	2	2	3	2	3
Cyrtina	2	...	1	...	...
Discina	2	1	2	11	14
Lingula	5	4	3	3	8
Orthis	7	4	8	8	25
Productus	45	32	28	47	109
Rhynchonella	17	3	11	11	36
Retzia	3	1	1	3	12
Spirifera	30	21	30	48	108
Spiriferina	3	5	5	3	9
Streptorhynchus . . .	4	7	5	3	10
Terebratula	4	3	2	8	26
	140	94	115	153	391

The preponderance of the two genera *Productus* and *Spirifera* is a great feature in the Carboniferous rocks. *Chonetes*, *Rhynchonella*, and *Orthis* follow in importance so far as the number of species lends significance. Five genera and 6 species of Brachiopoda pass to the Permian; they are *Camarophoria globulina*, *C. Schlotheimi*, *Discina Koninckii*, *Lingula Credneri*, *Spirifera Clannyana*, and *Spiriferina cristata*. Only 8 species of all classes pass to the Permian or higher rocks out of the Carboniferous system; out of these 8, 6 are Brachiopoda.

Pelecypoda.—*Monomyaria.*[1] This group and the Dimyaria united number no less than 50 genera and 386 species. The group Monomyaria, up to the present time, is represented by 11 genera and 163 species, 95 of which belong to the genus *Aviculopecten* alone, 26 to *Avicula*, *Pinna* 5, *Posidonomya* 13, *Pterinæa* 3, *Pteronites* 8, *Streblopteria* 3, *Gervillia* 2, *Inoceramus* 4, *Lima* 2, and *Anomia* 2. The Calciferous sandstones of Scotland and Northumberland have yielded 13 species, illustrating *Avicula*, *Aviculopecten*, and *Pteronites*; the Lower Limestone Shales 5 genera and 64 species; the Carboniferous limestone 11 genera and 151 species; the Yoredale rocks, through 4 genera, *Avicula*, *Aviculopecten*, *Pinna*, and *Posidonomya*, 14 species; the Millstone Grit, *Avicula*, *Aviculopecten*, and *Posidonomya*, and 11 species; the Lower Coal-measures the same genera and 13 species; while *Aviculopecten papyraceus* is the only species in the Upper Coal-measures.

[1] We retain this term here, including in it only the Asiphonida, represented by the Ostreidæ, Aviculidæ, and Pectinidæ

Those having the longest range are *Aviculopecten alternatus*, *A. gentilis*, *A. granosus*, *A. papyraceus*, *A. quadratus*, *A. scalaris*, and *A. variabilis*, *Posidonomya Becheri*, *P. lateralis*, and *P. membranacea*. The species of *Pteronites*, *Pterinæa*, *Streblopteria*, *Posidonomya*, *Pinna*, *Avicula*, and most of the *Aviculopectines* are chiefly from the Carboniferous limestone. We may assume that the largely represented group of the Aviculopectinidæ possessed much the same bathymetrical range as that of the genus *Pecten* in our modern seas; the same with *Pinna* and *Posidonomya*. Indeed, it would appear, from the persistency of the vertical range of the group Monomyaria, that no general depth governed their habit; for only 14 species out of the 162 range above the Carboniferous limestone and Yoredale beds, and the following may complete the species—*Aviculopecten fibrillosus*, *A. obtusus*, *Posidonomya Gibsoni*, and *Pinna spatula*. The accompanying table also includes the number of species that are in the Millstone Grit and Coal-measures. The magnitude of the Monomyarian group is sufficient reason for treating it separately, especially so when one genus alone (*Aviculopecten*) is represented by 95 species.

TABLE XXXII.—*Distribution of the Pelecypoda (Monomyaria).*

	England.	Scotland.	Ireland.	Belgium.	America.
Anomia	...	2	1	...	...
Avicula	16	10	23	25	24
Aviculopecten . . .	48	50	80	33	50
Gervillia	2	...	2	...	5
Inoceramus	...	...	4	1	1
Lima	...	...	2	...	1
Pecten	...	...	1	...	6
Pinna	5	4	5	3	6
Posidonomya . . .	8	2	8	5	9
Pterinæa	1	...	3	...	9
Pteronites	3	6	7	...	2
	83	74	136	67	113

The preponderance of species in one genus, as in *Aviculopecten*, is unexampled in any other British formation. One hundred and fifty species occur in Britain and Europe; 50 have been described from America, and all differ from our forms. The species occurring in the Belgian Carboniferous rocks are known to us through the researches of Professor de Koninck. In Ireland the Integropallialia appear to have been exhaustively recorded, mainly through the researches of M'Coy and Baily. The genus *Avicula*, in the Irish Carboniferous rocks, numbers about 23 species, *Aviculopecten* 80, *Pecten* 1, *Pteronites* 7, *Posidonomya* 8, *Pterinæa* 3, *Pinna* 5. Scotland: *Avicula* 10, *Aviculopecten* 50, *Pinna* 4, *Posidonomya* 2, *Pteronites* 6. England: *Avicula* 16, *Aviculopecten* 48, *Pinna* 5, *Posidonomya* 8, *Pteronites* 3, and *Pterinæa* 1. These comparisons are important, as showing geographical distribu-

tion as well as age. The collective fauna illustrating this group in all Europe beyond Belgium does not exceed 50 species, showing either want of research or the small development of the Carboniferous rocks east of Rhenish Prussia.

Pelecypoda.—*Dimyaria.*[1]—No less than 39 genera and 223 described species occur in the British Carboniferous rocks, the largest number being in the true limestone (30 genera and 182 species); the underlying Lower Limestone Shales yield 23 genera and 103 species; and the Calciferous beds of the North of England and Scotland 17 genera and 38 species.

Thus, the united British Pelecypod fauna numerically reaches 50 genera and 386 species, 163 being Monomyarian Asiphonida (Integropallialia), and 223 Siphonida (Sinupallialia). Hitherto we have not mentioned the Coal-measure Dimyaria, or those occurring in the Millstone Grit and Lower, Middle, and Upper Coal-measures. With the exception of the Lower Coal-measures, which have yielded 14 genera and 44 species, the three remaining horizons are comparatively poor, as would be anticipated from the estuarine condition or nature of the deposits. *Anthracosia*, *Anthracoptera*, *Axinus*, *Ctenodonta*, *Edmondia*, *Modiola*, *Myacites*, *Myalina*, and *Schizodus* are the genera that characterise the Coal-measures, or beds above the Yoredale series.

Six genera and 9 species are all that are known from the Millstone Grit; the genera are *Anthracosia* 2 species, *Axinus* 1, *Ctenodonta* 3, *Edmondia* 1, *Lunulacardium* (*Conocardium*) 1, *Myacites* 1.

The 14 genera in the Lower Coal-measures, with 44 species, are still more estuarine in habit, many allied to the Unionidæ and Myadæ. Numerically they are as follows:—*Anthracomya* 5 species, *Anthracosia* 6, *Anthracoptera* 2, *Axinus* 2, *Conocardium* 1, *Ctenodonta* 6, *Edmondia* 3, *Leptodomus* 1, *Modiola* 4, *Myacites* 4, *Myalina* 6, *Pleurophorus* 1, *Pullastra* 1, *Schizodus* 2. The Middle Coal-measures have as yet only yielded 4 genera and 16 species—*Anthracomya* 6 species, *Anthracosia* 6, *Anthracoptera* 2, and *Myalina* 2 species. The Upper Coal-measures contain the same 4 genera with 11 species.

The accompanying table gives the numerical value of 18 of the 39 English, Scotch, and Irish genera, with Belgium for comparison, which is the only country in Europe where the Carboniferous rocks are well developed. The researches of Professor de Koninck, of Liége, have afforded us data for this column. The relationship between the American fauna and our own is also appended, showing excess in the number of species in most of the genera. This holds good with the older Palæozoic genera also; but, through the Flora and Mollusca of the Coal-measures, America and Scotland (and, in a similar but less degree, Ireland) are intimately associated.

[1] Eighteen families, including the Arcadæ, Trigonidæ, and Unionidæ.

TABLE XXXIII.—*Eighteen of the chief Dimyarian Carboniferous Genera, showing their Specific or Numerical Value through the five Areas or Countries named.*

Genera.	England.	Scotland.	Ireland.	Belgium.	America.	Coal-Measures.
Allorisma (Myacites) . .	6	3	4	...	28	
Anthracomya . . .	8	2	1	...	2	Chiefly Coal-measures (6 species).
Anthracosia	10	9	...	23	8	Ditto (6 species).
Arca	4	6	10	17	7	
? Astarte	...	...	...	10	1	
Cardiomorpha . . .	9	6	5	36	13	
Conocardium . . .	6	2	10	8	13	
Ctenodonta	11	15	15	9	34	6 Coal-measures.
Cypricardia	7	9	10	16	11	
Edmondia	10	10	12	2	25	3 Coal-measures.
Modiola	10	8	12	...	5	4 Coal-measures.
Mytilus	3	2	3	30	6	
Myalina	6	9	1	3	18	6 Coal-measures.
Sanguinolites . . .	10	10	16	5	27	
Schizodus	3	8	7	...	13	2 Coal-measures.
Sedgwickia	...	2	7	...	6	
Solemya	3	...	1	5	5	
Solenopsis	...	1	1	7	...	
	106	102	115	171	222	33 in Coal-measures.

Solenoconchia.—The genus *Dentalium* is illustrated by 6 species; but none pass above the Carboniferous limestone. *D. priscum* is the only form that occurs in three horizons—the Calciferous sandstones, Lower limestones, and Carboniferous limestone. *D. scoticum* occurs only in the Calciferous sandstones.

Gasteropoda.—Two hundred and twenty-five species and 34 genera (if we include *Dentalium*), constitute the univalve fauna of the Carboniferous rocks; 29 genera and 202 species occur in and range through the limestone; thus, nearly every species occurs in this horizon. Sixteen of the 34 genera are distributed through the Carboniferous rocks of Europe and America, and are therefore of zoological as well as stratigraphical value. We append a table of these genera to accompany that showing the distribution of the Pelecypoda (Dimyaria). By comparison with the Molluscan fauna of Europe and America, we may hope to obtain some clue relative to the migration and dispersion of the Mollusca from some original area. These 16 chief genera are represented in England by 172 species, in Scotland by 90, in Ireland by 111, in Belgium (chiefly through de Koninck's researches) by 176,[1] and in the American Carboniferous

[1] Professor de Koninck's work upon the Carboniferous Mollusca has greatly added to our knowledge of the fauna of the Carboniferous rocks. (Fauna du Calc. Carb. de la Belg., vol. iii.)

rocks by nearly 200 species. This generic relationship with America is important as determining similarity of bathymetrical conditions, temperature, and food, and connection through coast-line, or land now lost. Nine genera and 21 species occur in the Scotch Calciferous sandstone—*Euomphalus* 4 species, *Lacuna* 1, *Littorina* 2, *Loxonema* 2, *Macrocheilus* 4, *Murchisonia* 3, *Natica* 1, *Naticopsis* 1, and *Pleurotomaria* 3.

The Lower Limestone Shales contain 50 species, which, with one exception (*Turbo appropinquans*), are also those of the Carboniferous limestone above.

The Yoredale beds (Upper Limestone Shales) are poor in Gasteropoda; only 7 genera and 10 species appear to be known. Both the Lower and Upper Limestone Shales are impure argillaceous rocks, and at the time of deposition were not favourable either to the presence or preservation of the Mollusca. The 7 genera are only represented by 10 species; they are—*Euomphalus catillus*, *Loxonema constricta*, *Macrocheilus curvilinea*, *M. imbricatus*, *M. rectilinea*, *Murchisonia fusiformis*, *Naticopsis plicistria* *Pleurotomaria limbata*, *P. tumida*, and *Turritella tenuistria*. The Millstone Grit, as we should expect, contains but a small Gasteropod fauna; such arenaceous deposits suited not the habits of this group of Mollusca; only 3 species are known—*Natica variata*, *Pleurotomaria limbata*, and *Murchisonia fusiformis*. The Pelagic Cephalopoda in the same beds, as we shall see, number no less than 33 species; but the sandy and muddy beds of the shore were not their habitat; they are not such good witnesses in the beds in which they are found as the ordinary Pelecypoda and Gasteropoda. The Lower Coal-measures alone yield Gasteropoda; none are known either in the Middle or Upper. Seven genera and 19 species are recorded from this division—*Euomphalus Gloveri*, *Littorina obscura*, *L. solida*, *Loxonema galvani*, *L. minutissima*, *L. Oweni*, *L. reticulata*, *Macrocheilus* 4 species, *Natica vetusta*, *Naticopsis plicistria*, *Pleurotomaria limbata*, *P. usocona*, and *Turritella*, 4 species.

Middle Coal-measures none.

Upper Coal-measures none.

TABLE XXXIV.—*Showing the Geographical Distribution of 16 characteristic Genera of Gasteropoda.*

	England.	Scotland.	Ireland.	Belgium.	America.
Acroculia	6	5	8	13	22
Chiton	3	3	4	15	2
Euomphalus	20	17	20	20	23
Littorina	2	1	...	2	...
Macrocheilus	17	8	12	5	19
Metoptoma	5	...	...	5	2
Murchisonia	16	7	6	19	20
Natica	8	9	9	14	16
Naticopsis	4	1	3	...	...
Patella	7	...	5	6	...
Phanerotinus	4	...	3	...	2
Platyschisma	5	2	4	1	4
Pleurotomaria	46	24	16	59	65
Turritella	11	1	4	...	2
Turbo	6	1	4	5	...
Loxonema	12	11	13	12	20
	172	90	111	176	197

Pteropoda.—The genus *Conularia* first occurs in the Carboniferous rocks in the Lower Limestone Shale, and ranges through all but the Upper Coal-measures. This genus dies out in the Coal-measures. Many of the nodules in the "Penny-stone" of Coalbrookdale contain fine examples of *C. quadrisulcata*, Sow., the only determined species known. An undetermined form occurs in the Calciferous sandstones of Woodhall, Scotland. America yields 17 species of *Conularia* to our two; *C. quadrisulcata* is not known out of Britain.

Heteropoda.—*Bellerophon* and *Porcellia* (the former with 25 species and the latter 4) exhaust the species in the Carboniferous rocks. At no period in Palæozoic times did so many species of *Bellerophon* exist in one formation. Twenty-four of the 25 species occur in the Carboniferous limestone, and 6 of these range higher, or into the Coal-measures; they are—*Bellerophon apertus*, *B. decussatus*, *B. Dumonti*, *B. hiulcus*, *B. Oldhamii*, and *B. Urii*. Four species (*B. costatus*, *B. decussatus*, and var. *undatus*, and *B. Urii*) are Calciferous or Tuedian species. Seventeen species essentially characterise the limestone. The Lower Coal-measures yield the same 4 species, with the addition of *B. navicula*, *B. Oldhamii*, and *B. Dumontii*. None occur in the Upper Coal-measures—this order, like many others in the Carboniferous series, dying out at its close, not to appear again.

Ireland has yielded 21 species of *Bellerophon*, Scotland 15, England 17, Belgium 25, and America 39 species. Only 19 species range through Europe, 8 of them being British.

Cephalopoda.—No fewer than 154 species are distributed through

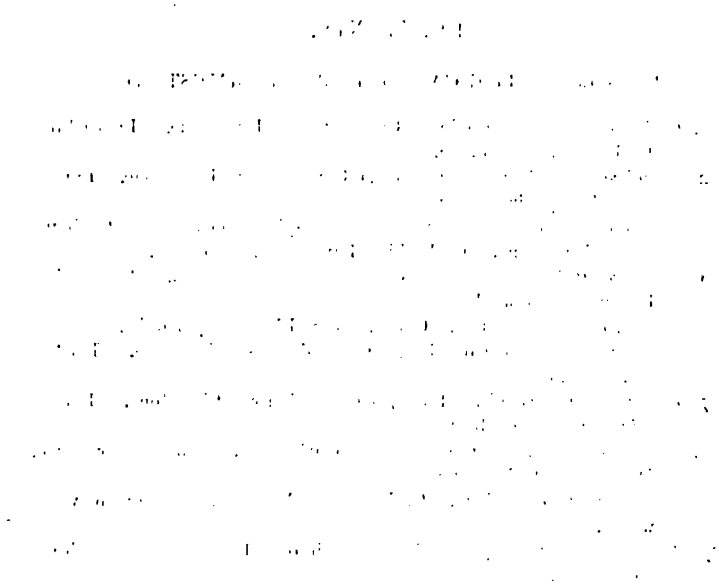

PLATE XIV.

FOSSILS OF THE CARBONIFEROUS LIMESTONE.

1. *Orthis resupinata* (Martin). Carboniferous Limestone. Lancashire, Derbyshire, Ireland, &c.
2. *Spirifera (rotundata) pinguis* (Sow.) Carboniferous Limestone. Lancashire, Derbyshire, Ireland, &c.
3. *Spirifera trigonalis* (Martin). Showing spiral appendages. Carboniferous Limestone. Derbyshire, Lancashire, Arran, &c.
4. *Spirifera striata* (Martin). Carboniferous Limestone. Lancashire, Derbyshire, Ireland, &c.
5. *Spirifera glabra* (Martin). Carboniferous Limestone.—*passim.*
6. *Spirifera cuspidata* (Martin). Carboniferous Limestone. Bristol, Yorkshire, &c.
7. *Rhynchonella pleurodon* (Phill.) Carboniferous Limestone. Lancashire, Ireland, Derbyshire.
8. *Rhynchonella acuminata* (Mart.) Carboniferous Limestone. Yorkshire, Derbyshire, Ireland, &c.
9. *Terebratula hastata* (Sow). Carboniferous Limestone. Common everywhere.
10. *Productus punctatas* (Martin). Carboniferous Limestone. Yorkshire, Derbyshire, &c.

PLATE XIV.

FOSSILS OF THE CARBONIFEROUS LIMESTONE.

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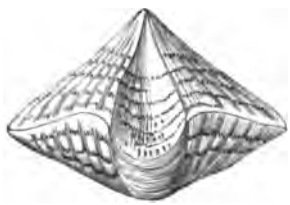

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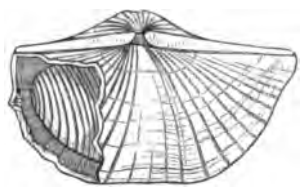

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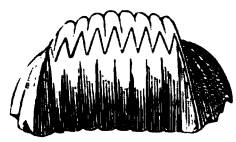

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the British Carboniferous system. Four genera and 6 species occur in the following order in the Calciferous or Tuedian beds, 5 genera and 22 species in the Lower Limestone Shale, 8 genera and 140 species in the Carboniferous limestone; 5 genera and 33 species are Yoredale; 3 genera and 30 species are Millstone grit; 3 genera and 24 species occur in the Lower Coal-measures, 3 genera and 6 species in the Middle, and 1 genus and 2 species in the Upper Coal-measures. These 154 species represent 8 genera—*Actinoceras*, 1 species, *Cyrtoceras* 1, *Discites* 18 (subgenus of *Nautilus*), *Goniatites* 53, *Nautilus* 32, *Orthoceras* 40, *Poterioceras* 2, and *Trigonoceras* 3 species.

The accompanying table of the 8 British genera shows the number of species in each country, including, as in the two prior tables, Belgium and America for comparison, in which it will be seen that the 154 species are thus distributed,—in England 118, in Scotland 63, in Ireland 109, and in Belgium 90. Comparison carried beyond Europe to America, as before, shows generic affinity through 114 species, hardly a single form being exclusively British. All Europe appears only to yield 95 species through 11 areas; research and the accident of our possessing these rocks highly developed account for our list of Molluscan fauna being so extensive.

TABLE XXXV.—*The Eight British Genera of Cephalopoda.*

	England.	Scotland.	Ireland.	Belgium.	America.
Actinoceras	1	1	1	1	2
Cyrtoceras	2	3	...	8	5
Discites	10	3	14	4	1
Goniatites	49	15	32	25	32
Nautilus	18	14	21	22	54
Orthoceras	33	24	36	29	20
Poterioceras	2	3	2	...	...
Trigonoceras . . .	3	...	3	1	...
	118	63	109	90	114

Pisces.—One hundred and twenty-seven genera and 353 species of fish, with 21 genera and 26 species of Amphibia, numerically comprise the Vertebrate fauna of the British Carboniferous rocks. The comparatively rich assemblage of ichthyic remains in the Old Red Sandstone bears no proportion to the great increase and development of this class in the Carboniferous system. Only two orders are represented, viz., the Ganoidei and Elasmobranchi (*Placoidei*, Ag.), the Ganoidei through the suborder Crossopterygidæ by 4 of the 6 recognised families, the Saurodipterini, Glyptodipterini, Ctenodipterini? (Dipnoi),[1]

[1] Dr. Traquair would remove the Glyptodipterini from the Crossopterygious Ganoids and place them sectionally in the order Dipnoi (*vide* Trans. Roy. Soc. Edinb., vol. xxvii., for the sections and families proposed by Dr. Traquair).

and Cœlacanthini. The Elasmobranchi mainly correspond to the Chondropterygidæ or the Cartilaginous Fishes of Cuvier (the Holocephali and Plagiostomi of Owen and the Selachia of Müller).

The distribution and appearance in time of the two orders seems to have been much the same; the Plagiostomi first appeared in the Ludlow rocks, the Holocephali through the Chimæroids in the Devonian rocks of North America (*Rhinodus* of Newberry). The section Cestraphori of the order Plagiostomi is abundantly represented in the Carboniferous rocks from base to summit, spines and teeth of the several genera occurring everywhere, although very locally—the *Ctenacanthi*, *Gyracanthi*, *Homacanthi*, *Oracanthi*, *Onchi*, and *Leptacanthi* being the most important, and occurring as defence spines (Ichthyodorulites).

The genera or groups illustrated by palatal and other teeth are *Cochliodus*, *Deltodus*, *Psammodus*, *Petalodus*, *Orodus*, *Ctenoptychius*, *Cladodus*, *Glossodus*, *Diplodus*, *Helodus*, &c. Many of these genera will be reduced under stricter and more complete research.[1]

The lowest recognised rocks of the Carboniferous system, the "Calciferous Sandstone" of the Scotch geologists, or Tuedian of Northumberland, confined to the North of England and South-Eastern Scotland, contain 13 genera and 14 species—*Cladodus*, *Ctenacanthus*, *Ctenodus*, *Ctenoptychius*, *Diplodus*, *Eurynotus*, *Megalichthys*, *Nematoptychus*, *Pœcilodus*, *Rhadinichthys*, *Rhizodus*, and *Wardichthys*. With one exception each genus is represented only by 1 species.

The Lower Limestones and Shales have yielded 29 genera and 50 species; and if this lower member be associated with the thick or Carboniferous limestone, they together represent 80 genera and 170 species, 17 genera and 22 species being peculiar to these Lower limestone shales. Closer research will probably show that the 17 genera now known to occur only in the Lower limestone exist in the succeeding series.

Carboniferous Limestone.—This grandly developed group of rocks in the British Islands has yielded no less than 63 genera and 147 species of fishes; but the Yoredale series which succeed them yield none; and only 3 genera and 3 species are known in the Millstone Grit (*Megalichthys Hibberti*, *Rhizodus Hibberti*, and *Acanthodes Bronni*). This sudden cessation or non-occurrence can scarcely be accounted for on lithological grounds, or original sedimentary accumulation, such as would be applicable to the habits of certain genera of the Mollusca.

Thirty-eight genera of Placoidei are confined to the Carboniferous limestone, and 12 genera of the same order are from both Lower limestone shale and Carboniferous limestone. On the other hand, it is remarkable that only 6 genera of Ganoidei are strictly confined

[1] Consult "The Fossil Fishes of the Carboniferous Limestone of Great Britain," in Scientific Transactions, Royal Dublin Soc., vol. i., Series II. W. C. Davis, 1883.

to that horizon; they are *Acrolepis, Asterolepis, Coccosteus? Cycloptychius, Phyllolepis,* and *Platycanthus.*[1]

We are in doubt as to the real position of the Upper limestones of Durham and Northumberland, or what, if any, should be assigned to the Yoredale group. Nevertheless, we are not aware of any Vertebrate occurring in the Yoredale beds. The Millstone Grit, as before stated, has only yielded evidence of 3 genera and 3 species, and these in the form of scales.

Lower Coal-measures.—Whatever conditions may have caused so complete a zoological break in the distribution of the fishes in the British Carboniferous rocks during their deposition, the return of the same genera and many of the same species in the Lower Coal-measures is equally important. We have evidence of the remains of 52 genera and 112 species, the whole composed nearly equally of the orders Placoidei and Ganoidei. The numbers may be thus expressed:—In the Lower Coal-measures 32 genera and 50 species of Ganoidei occur, in the Middle Coal-measures 5 genera and 6 species, in the Upper Coal-measures 6 genera and 8 species. The Placoidei are represented in the Lower by 22 genera and 40 species, in the Middle by 10 genera and 14 species, and in the Upper by 6 genera and 8 species. Regarding the Coal-measure fishes of Britain as a whole, they are, numerically, Lower Coal-measures, 52 genera and 112 species; Middle, 14 genera and 20 species; and Upper, 12 genera and 14 species. The numerical distribution for Britain and Belgium is—

England	136 species.
Scotland	152 „
Ireland	120 „
Belgium	50? „

Amphibia.—Of the 4 orders in the class Amphibia, the Labyrinthodontia alone occur in the Carboniferous rocks. Twenty-one genera and 26 species are known in Britain. Without exception they all occur in one or the other of the divisions of the Coal-measures.

Professor de Koninck, in his great work ("Ann. du Mus. Roy. d'Hist. Nat. de Belg.," tome ii., Faune du Calc. Carb. de la Belg., pt. i.), has described 29 genera and 44 species, all from the Carboniferous limestone. The fauna of the Coal-measures in Belgium is small compared with that of Britain.

The Belgian Lower Coal-measure genera are *Amphicœlosaurus, Amphisaurus, Anthracerpeton, Brachyscelis, Batrachiderpeton, Discospondylus, Dolichosoma, Erpetocephalus, Ichthyerpeton, Keraterpeton, Lepterpeton, Loxomma, Ophiderpeton, Labyrinthodontosaurus, Leptognathosaurus, Macrosaurus, Megalocephalus, Orthosaurus, Parabatrachus, Pholidogaster, Streptodontosaurus,* and *Urocordylus.*

The Middle Coal-measures yield *Anthracosaurus, Megalerpeton,* and *Pholiderpeton.*

[1] The Ganoid Fishes are under revision by Dr. Traquair, whose accurate knowledge of the order will be brought to bear upon their structure and classification.

Loxomma and *Pteroplax* occur in both Lower and Upper Coal-measures.

We are chiefly indebted to Professors Huxley[1] and Miall[2] for elaborate researches into the structure and affinities of the extinct order Labyrinthodontia, a group eminently characteristic of Carboniferous time; for, with the exception of *Rhinosaurus* from the Lias and the Jurassic *Brachyops*, no remains of this order have hitherto been discovered in rocks younger than the Trias.

[1] Article "*Amphibia*," Encyclop. Britannica, 9th ed. 1875. "A Description of Vertebrate Remains from the Jarrow Colliery, Kilkenny," Trans. Roy. Irish Academy, vol. xxiv.

[2] Miall: "Report on the Labyrinthodonts of the Coal-measures," Brit. Assoc. 1873. "A Report on the Structure and Classification of the Labyrinthodonts," Brit. Assoc. 1874.

PLATE XV.

FOSSILS OF THE COAL-MEASURES.

1. *Sigillaria pachyderma* (Lindl.) Coal-measures. Northumberland, &c.
2 *Pecopteris*, sp. Coal-measures—*passim.*
3. *Neuropteris Loshii* (Brong.) Coal-measures. Newcastle, Yorkshire, &c., &c.
4. *Sphenopteris Höninghausii* (Brong.) Coal-measures. Newcastle, &c.
5. *Annularia* (*Asterophyllites*) *brevifolia.* Coal-measures.
6. *Sphenophyllum dentatum* (Brong.) Coal-measures. Newcastle, &c.
7. *Walchia hypnoides?* Trias.

PLATE XV.

FOSSILS OF THE COAL-MEASURES.

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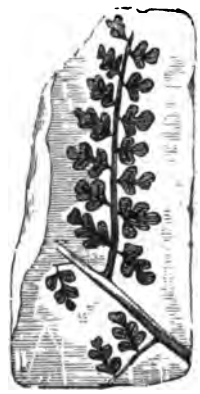

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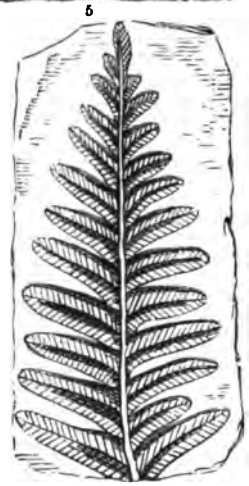

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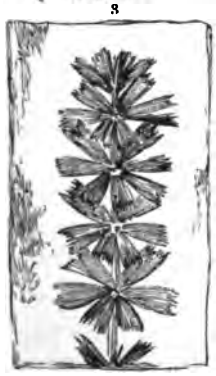

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TABLE XXXVI.—*Showing Stratigraphical and Zoological Distribution of the Carboniferous Species.*

From Devonian.	Classes.	Genera.	Species.	Calciferous Sandstone.	Lower Limestone Shales, &c.	Carboniferous Limestone.	Yoredale Beds.	Millstone Grit.	Lower Coal-Measures.	Middle Coal-Measures.	Upper Coal-Measures.	Species that pass to the Permian.
4	Plantæ	75	328	19	22	44	...	19	44	24	22	4
	Protozoa { Spongida	8	14	...	3	14	...	...	...	...	...	...
	Protozoa { Foraminifera	15	43	4	19	16	1	1	...	...	...	...
	Hydrozoa	2	3	...	1	2	...	...	...	...	...	...
	Actinozoa	39	144	4	18	121	4	...	...	...	...	...
2	Echinodermata	27	139	4	11	117	...	...	...	...	...	...
2	Annelida	11	34	1	6	10	1	2	1	1	1	...
1	Crustacea	38	173	13	17	28	5	1	13	3	10	1
	Arachnida	3	4	...	...	...	...	...	2	1	...	...
	Myriapoda	2	4	...	...	...	...	...	3	1	...	...
	Insecta	3	3	...	...	...	...	...	3	...	...	...
	Polyzoa	25	78	4	13	11	1	...	1	...	?	5
4	Brachiopoda	19	175	15	16	114	1	14	16	3	1	...
10	Lamellibranchiata { Monomyaria	11	163	13	5	111	4	3	13	4	4	...
4	Lamellibranchiata { Dimyaria	39	223	11	12	101	1	1	11	1	1	...
	{ Solenoconchia	1	6	4	1	1	...	...	...	...	...	...
	{ Gasteropoda	33	219	21	16	101	1	3	1	...	...	...
3	Pteropoda	1	1	1	1	1	1	1	1	1	...	...
1	Heteropoda	2	29	1	1	14	1	1	1	1	...	...
1	Cephalopoda	9	154	4	3	60	5	3	5	3	1	...
3	Pisces	127	353	13	10	63	...	3	13	6	2	...
	Amphibia	21	26	...	...	...	...	...	4	2	1	...
51		511	2316	88	118	815	49	44	118	70	43	13
				167	108	1637	197	116	118	198	118	

TABLE XXXVII.—ORGANIC REMAINS OF THE CARBONIFEROUS STRATA.[1]

PLANTÆ.

Genera.	No. of Species.	Localities.
Adiantites	4	Newcastle.
Alethopteris	10	Newcastle, Wales, Somerset.
Anabathra	1	Berwickshire.
Annularia	2	Somersetshire.
Antholithes	2	Salop, Newcastle.
Aphlebia	1	Newcastle.
Archagaricon	4	"
Aspidiaria	5	Somerset, Yorkshire.
Asterophyllites	12	Newcastle, Salop, Somerset.
Bechera	2	Salop.
Bothrodendron	1	
Bowmanites	1	Manchester.
Calamites	12	Yorkshire, Lancashire.
Calamodendron	1	Lancashire.
Cardiocarpon	4	Newcastle.
Carpolithes	5	Jarrow, Newcastle.
Caulopteris	3	Somerset.
Chondrites	1	Salop.
Cordaites	2	Scotland, &c.
Coryneopteris	1	Yorkshire.
Cycadites	1	Scotland.
Cyclocladia	1	Newcastle.
Cyclopteris	8	Yorkshire, Salop, Newcastle.
Cyclostigma	1	Ireland.
Cyperites	1	Leebotwood, Salop.
Dadoxylon	2	Newcastle.
Dictyoxylon	1	(?)
Dictyophyllum	1	Ireland.
Diploxylon	1	Yorkshire.
Endogenites?	1	Salop.
Eremopteris	1	Northumberland.
Flabellaria	1	Cumberland, Salop.
Halonia	5	Yorkshire, Salop.
Hydatica	2	Yorkshire.
Hymenophyllites	2	Newcastle.
Knorria	4	Newcastle, Salop.
Lepidodendron	22	England, Wales, Scotland.
Lepidophyllum	4	Somerset, Newcastle.
Lepidostrobus	8	Newcastle, Salop, Somerset.
Lomatophloios	1	Edinburgh.
Lychnophorites	1	Yorkshire.
Lycopodites	2	Newcastle, Durham.
Lyginodendron	1	Ayrshire.
Macrostachya	1	Newcastle.
Musocarpum	1	Lancashire.
Myriophyllites	2	Yorkshire, Durham.
Neuropteris	23	England, Wales.
Noeggerathia	2	Newcastle, Lancashire.

[1] See Plates Nos. XI., XII., XIII., XIV., and XV. for many characteristic species.

Genera.	No. of Species.	Localities.
Odontopteris	4	Yorkshire, Staffordshire.
Otopteris ?	1	Clee Hills.
Palæophytis	1	Scotland.
Palmacites	1	Salop.
Pecopteris	29	England, Wales, Scotland.
Peuce	1	Durham.
Picea	1	„
Pinites	5	Newcastle, Berwickshire.
Pinnularia	1	Salop.
Pitus	2	Berwickshire.
Poacites	2	Devon, Lancashire.
Pothocites	1	Near Edinburgh.
Protopteris	1	Whitehaven.
Rhabdocarpus	1	Newcastle.
Sagenaria	7	Yorkshire, Newcastle.
Selaginites	1	Edinburgh.
Sigillaria	31	England, Scotland, and Wales.
Sphenophyllum	4	Somerset, Newcastle, &c.
Sphenopteris	34	England, Wales, Scotland.
Sternbergia	1	Scotland, England, Wales.
Stigmaria	3	England, Wales, Scotland.
Trigonocarpon	6	Lancashire, Salop, Somerset.
Ulodendron	11	Edinburgh, Newcastle, &c.
Vetacapsula	1	Dudley.
Volkmania,	1	„
Walchia ?	1	„
Woodwardites	1	„
75	328	

SUB-KINGDOM—PROTOZOA (*Spongida*).

Doryderma	1	Scotland, Ireland.
Geodia	1	Scotland.
Haplistion	1	„
Hyalostelia	2	„
Holasterella	4	„
Pachastrella	1	„
Palæacis	3	„
Tragos	1	Ireland.
8	14	

Foraminifera.

Amphistegina	1	Universally distributed through the Carboniferous Limestones in most localities.
Archæodiscus	1	
Bigeneriana	1	
Climacammina	1	
Dentalina	2	
Endothyra	10	
Haplophragmium	1	
Lagena	3	
Lituola	2	
Nodosinella	5	
Nodosaria	1	
Saccammina	1	
Stacheia	6	
Textularia	2	
Trochammina	6	
15	43	

Sub-Kingdom—Cœlenterata.

Class—Hydrozoa.

Genera.	No. of Species.	Localities.
Palæocoryne	2	Scotland.
Arbusculites	1	
2	3	

Class—Actinozoa.

Genera.	No. of Species.	Localities.
Amplexus	6	Distributed Geographically in the British Islands through the Carboniferous Limestone series.
Aspidophyllum	4	
Astræopora	1	
Aulopora	3	
Aulophyllum	1	
Beaumontia	2	
Campophyllum	2	
Chetetes	4	
Cladochonus	5	
Clisiophyllum	8	
Columnaria (Beaumontia)	2	
Cyathaxonia	2	
Cyathophyllum	10	
Cyclophyllum	2	
Dendropora	1	
Dibunophyllum	3	
Diphyphyllum	3	
Favosites	5	
Fistulipora	2	
Gorgonia ?	2	
Heterophyllia	8	
Iania	1	
Konninckophyllum	6	
Lithostrotion	22	
Lonsdaleia	4	
Lophophyllum	1	
Michelinia	4	
Mortieria	1	
Petalaxis	1	
Rhodophyllum	5	
Rhabdopora	1	
Sarcinula	3	
Stenopora	1	
Phillipsastræa	2	
Pyrgia	1	
Strombodes	1	
Syringopora	5	
Verticilopora	1	
Zaphrentis	8	
39	144	

SUB-KINGDOM.—ANNULOIDA.

Class.—ECHINODERMATA.

BLASTOIDEA.

Pentremitidæ.

Genera.	No. of Species.	Localities.
Codonaster.	2	Yorkshire, Derbyshire.
Pentremites	13	England, Wales, Ireland.
Pentephyllum	1	Ireland.
3	16	

Palæchinidæ.

Archæocidaris	5	Yorkshire, Derbyshire, Ireland.
Melonites	1	Ireland.
Palæchinus	5	Yorkshire, Ireland.
Perischodomus	1	Wexford.
Protoechinus	1	Ireland.
Rhoechinus	1	Hookhead, Wexford.
6	14	

Crinoidea.

Actinocrinus	21	England, Wales, and Ireland.
Astrocrinites	2	Yorkshire, Scotland.
Atocrinus	1	Ireland.
Cupressocrinus	2	Derbyshire.
Cyathocrinus	10	Yorkshire, Derbyshire.
Dichocrinus	3	Yorkshire, Somerset.
Euryocrinus	1	Yorkshire.
Hydreionocrinus	3	"
Mespilocrinus	1	"
Phillipsocrinus	1	Ireland.
Pisocrinus	1	Yorkshire.
Platycrinus	23	England, Wales, Ireland.
Poteriocrinus	20	" "
Rhodocrinus	8	Yorkshire, Gloucestershire, &c.
Sycocrinus	3	Yorkshire.
Synbathocrinus	1	Yorkshire, Bristol.
Taxocrinus	4	Fermanagh, Yorkshire.
Woodocrinus	4	Yorkshire.
18	109	

SUB-KINGDOM.—ANNULOSA.

Class.—ANNELIDA.

Arenicola	1	Lancashire, &c.
Crossopodia	2	Durham.
Euphoberia	2	Coalbrook Dale.
Nemertites	1	Scotland.
Ortonia ?	1	
Sabella	1	Ireland.

Genera.	No. of Species.	Localities.
Serpula	7	Manchester, Salop, &c.
Serpulites	3	Lancashire, Ireland.
Spiroglyphus	1	Ireland.
Spirorbis	14	"
Xylobius	1	Yorkshire.
11	34	

Class—CRUSTACEA.

Entomostraca.

Apus	1	Distributed through the Carboniferous group, both in the Limestones and Shales and Coal-measures.
Beyrichia	5	
Bairdia	2	
Bradycinetus	1	
Candona	2	
Carbonia	2	
Cypridina	12	
Cypridella	6	
Cyprella	3	
Cypridinella	6	
Cypridellina	9	
Cypris?	4	
Cythere	27	
Cytherella	4	
Ceratiocaris	2	
Dithyrocaris	6	
Entomoconchus	4	
Entomis	1	
Estheria	9	
Kirkbya	10	
Leaia	3	
Leperditia	7	
Moorea	2	
Offa	1	
Philomedes	1	
Polycope	3	
Rhombina	2	
Sulcuna	2	
28	137	

Limulidæ.

Prestwichia	3	Coal-measures.
Belinurus	1	
2	4	

Merostomata.

Eurypterus	2	Scotland.

Macrura.

Anthrapalæmon	3	Scotland.
Palæocrangon	1	Scotland and Yorkshire.
Pygocephalus	3	Scotland, Lancashire.
3	7	

Family—*Trilobita.*

Genera.	No. of Species.	Localities.
Brachymetopus	3	Distributed through the Carboniferous Limestone.
Cyclus (*Phyllopoda*)	7	
Griffithides	5	
Phillipsia	8	
4	23	

ARACHNIDA.

Phalangidæ.

Architarbus	1	Lancashire.
Eophrynus	1	Coalbrook Dale, Dudley.
Eoscorpius	2	Staffordshire.
3	4	

Myriapoda.

Euphoberia	3	Staffordshire.
Xylobius	1	Scotland.
2	4	

Class—INSECTA.

Locustidæ.

Curculioides	1	Coalbrook Dale.
Gryllacris	1	Coalbrook Dale.
2	2	

Mantidæ.

Lithomantis	1	Scotland.

SUB-KINGDOM—MOLLUSCOIDA.

Class—POLYZOA.

Actinostoma	1	Scotland.
Archæopora	1	,,
Ascodictyon	1	,,
Carinella	1	,,
Cellepora	1	Derbyshire.
Ceriopora	5	Yorkshire, Ireland.
Diastopora	1	Wexford.
Fenestella	25	England, Ireland, Scotland.
Glauconome	8	Yorkshire, Ireland.
Goniocladia	1	Scotland.
Hemitrypa	1	South of Ireland.
Hyphasmopora	1	Scotland.
Ichthyorachis	1	Clare.
Orbiculites	1	Ireland.
Polypora	8	Yorkshire, Ireland.
Ptylopora	2	,, ,,
Pustulipora	2	,, ,,
Retepora	2	Lanarkshire, Ireland.
Rhabdomeson	3	Devon, Scotland.
Rhombopora	1	Scotland.
Stomatopora	1	,,
Sulcoretepora	2	Yorkshire, Ireland.
Synocladia	2	Scotland.
Thamniscus	2	,,
Vincularia	4	Ireland.
25	78	

SUB-KINGDOM MOLLUSCA (*Molluscoida*)

Class.—BRACHIOPODA.

Genera.	No. of Species.	Localities.
Athyris	10	Northumberland, Derbyshire, Ireland.
Camarophoria	4	Derbyshire, &c.
Chonetes	16	Northumberland, Yorkshire, Ireland, &c.
Crania	3	,, ,,
Cyrtina	2	Derbyshire, Yorkshire, &c.
Discina	3	Ireland, Yorkshire, &c. &c.
Hypodema	1	Derbyshire.
Lingula	5	Yorkshire, Derbyshire, Ireland, &c.
Orthis	6	Ireland, Yorkshire, &c. &c.
Productus	45	England, Ireland, Scotland, Wales.
Retzia	3	Yorkshire, S. Wales, &c.
Rhynchonella	21	England, Scotland, Ireland, Wales.
Spirifera	35	British Islands (*passim*).
Spiriferina	4	,, ,,
Streptorhynchus	5	,, ,,
Strophalosia	1	Yorkshire, &c. &c.
Strophomena	1	Yorkshire, Derbyshire.
Syringothyris	3	Derbyshire.
Terebratula	7	British Islands.
19	175	

SUB-KINGDOM.—MOLLUSCA (*Conchifera*).

PELECYPODA (*Lamellibranchiata*).

Monomyaria.

Anomia	2	Ireland, Scotland.
Avicula	26	Yorkshire, Ireland.
Aviculopecten	95	Ireland, Yorkshire, &c.
Gervillia	2	Yorkshire, Fermanagh.
Inoceramus?	4	Ireland.
Lima?	2	,,
Pinna	5	Derbyshire, &c., &c.
Posidonomya	13	Fermanagh, Derbyshire.
Pterinea?	3	Tyrone.
Pteronites	8	Ireland.
Streblopteria	3	Ireland, Yorkshire.
11	163	

Dimyaria.

Anatina	2	Ireland.
Anodontopsis	2	,,
Anthracoptera	4	Lancashire.
Anthracomya	10	S. Wales, Scotland, Lancashire, &c.
Anthracosia	9	,, ,,
Arca	9	Ireland, &c.
Cardiomorpha	9	Ireland, Yorkshire.

Genera.	No. of Species.	Localities.
Conocardium (Pleurorhynchus)	11	Ireland, Yorkshire, Derbyshire.
Corbis?	1	Ireland.
Cucullæa	5	Yorkshire, Ireland.
Curtonotus	4	North Devon.
Cypricardia	14	Ireland, Yorkshire, Northumberland.
Ctenodonta	27	Derbyshire, Lancashire.
Dolabra?	7	Ireland.
Donax?	1	,,
Edmondia	16	Ireland, Yorkshire.
Leda	2	Ireland, Derbyshire, Northumberland.
Leptodomus	3	Ireland, Yorkshire, Lanarkshire.
Lithodomus	2	Derbyshire, Northumberland.
Lucina?	2	Yorkshire, Ireland.
Lutraria?	2	Ireland.
Mactra?	2	,,
Modiola	17	Ireland, Yorkshire.
Myacites	7	Ireland, Derbyshire.
Myalina	11	Lanarkshire, Salop.
Mytilus	3	Ireland.
Pandora?	1	,,
Pleurophorus	1	Weardale, Durham.
Psammobia?	1	Ireland.
Pullastra?	2	,,
Sanguinolites	10	Ireland, Northumberland.
Schizodus	8	England, Wales, and Scotland.
Sedgwickia	7	Ireland.
Solemya	3	Northumberland, Ireland.
Solenopsis	1	Derbyshire.
Teredo?	1	Ireland.
Unio?	3	Edinburgh, Salop, &c.
Venus?	1	Northumberland, Yorkshire, &c.
Venerupis	2	Derbyshire.
39	223	

Pteropoda.

Conularia	1	Lanarkshire, Bristol, Coalbrook Dale, &c. &c.

Class.—GASTEROPODA.

Acroculia	8	Ireland, Yorkshire, Derbyshire.
Cerithioides	2	Ireland.
Chiton	7	Scotland.
Chitonellus	2	,,
Cylindrites	1	Derbyshire, &c.
Dentalium (Solenoconchia)	6	Ireland, Westmoreland.
Dirinus	1	Ireland.
Elenchus	2	,,
Eulima	2	Yorkshire.
Euomphalus	24	England, Wales, Ireland.
Fissurella	1	Ireland.
Lacuna?	1	,,
Littorina	3	,,
Loxonema	16	Ireland, Derbyshire, Yorkshire.
Macrocheilus	19	,, ,,
Melania	1	Kendal.

Genera.	No. of Species.	Localities.
Metoptoma	5	Derbyshire, Yorkshire.
Murchisonia	16	Ireland, Yorkshire, Derbyshire.
Natica	8	Northumberland, Yorkshire, Ireland, &c.
Naticopsis	4	Ireland, &c.
Nerita	2	Ireland, Bristol.
Patella	8	Yorkshire, Ireland.
Phanerotinus	4	„ „
Portlockia	1	Yorkshire.
Platyschisma	7	Ireland, Derbyshire.
Pleurotomaria	53	Ireland, Derbyshire, &c.
Scalites	1	Yorkshire.
Siphonaria	1	Ireland.
Trochus	2	Yorkshire, Derbyshire.
Trochella	1	Yorkshire.
Turbo	3	Yorkshire, Ireland.
Turbonillina	1	Yorkshire.
Turbonitella	1	„
Turritella	11	„
34	225	

HETEROPODA (*Nucleobranchiata*).

Bellerophon	25	Yorkshire, Ireland, Derbyshire, &c.
Porcellia	4	Lanarkshire, Yorkshire.
2	29	

Class—CEPHALOPODA.

Actinoceras	1	Dumfriesshire, Ireland, Lancashire.
Cyrtoceras	4	Derbyshire, Yorkshire.
Discites	18	Ireland, Derbyshire, Yorkshire.
Goniatites	53	Yorkshire, Ireland, Derbyshire, &c.
Nautilus	32	Ireland, Dumfriesshire, Derbyshire, Lancashire, &c. &c.
Orthoceras	40	Yorkshire, Ireland, Lancashire.
Phragmoceras ?	1	Lancashire, Yorkshire.
Poterioceras	2	Dumfriesshire, Yorkshire, Lancashire.
Trigonoceras	3	Ireland.
9	154	

SUB-KINGDOM—VERTEBRATA.

Class—PISCES.

Acanthodes	4	Near Edinburgh.
Acondylacanthus	7	Armagh, Northumberland, Derbyshire.
Acrolepis	1	Derbyshire, Scotland.
Aganacanthus	1	Scotland.
Aganodus	2	Northumberland.
Amphicentrum [1]	1	„
Anodontocanthus	3	Yorkshire, Scotland.

[1] ? Cheirodus.

Genera.	No. of Species.	Localities.
Archichthys	1	Ireland, Northumberland.
Asterolepis	1	Armagh.
Asteroptychius	3	,,
Bothriolepis?	1	,,
Canobius	5	Eskdale.
Carcharopsis	3	Armagh.
Chalazacanthus	1	Bristol.
Characodus	3	Armagh.
Cheirodus	2	Derbyshire, Staffordshire, &c.
Cheirodopsis	1	Eskdale.
Chelyophorus	1	Ireland.
Chomatodus	6	Armagh, Bristol, Yorkshire.
Cladacanthus	2	Armagh.
Cladodus	13	Armagh, Bristol, Derbyshire, &c.
Coccosteus?	1	Armagh.
Cochliodus	2	Armagh, Bristol.
Cœlacanthus	4	Halifax, Armagh, &c.
Colonodus	1	Armagh.
Copodus	4	Ireland, Northumberland.
Compsacanthus	3	Yorkshire, Armagh.
Cosmacanthus	4	Armagh.
Cosmoptychius	1	Edinburgh.
Cricacanthus	1	Armagh.
Cycloptychius	2	Staffordshire, Eskdale.
Ctenacanthus	19	Armagh, Bristol, Dalkeith.
Ctenodus	9	Yorkshire, Manchester, &c.
Ctenopetalus	2	Yorkshire, Armagh.
Ctenoptychius	10	Armagh, Glasgow, Manchester.
Deltodus	3	Armagh, Derbyshire.
Deltoptychius	2	Armagh, Bristol, Ireland.
Diclitodus	1	Yorkshire.
Dimyleus	1	,,
Diplodus	3	Lancashire, Edinburgh, &c.
Dipriacanthus	2	Armagh.
Elonichthys	4	Staffordshire, Scotland.
Erismacanthus	1	Armagh, Northumberland.
Eurynotus	2	Edinburgh.
Fissodus	1	Scotland.
Ganolodus	2	Northumberland.
Glyphanodus	1	Yorkshire, Lancashire.
Glossodus	2	Armagh.
Gnathacanthus	2	,,
Gonatodus	3	Edinburgh.
Gyracanthus	5	Scotland, Yorks., Wales, Ireland.
Harpacodus	2	Armagh.
Helodus	13	Armagh, Bristol, Lanarkshire.
Hoplonchus	1	Yorkshire.
Holurus	3	Scotland.
Homacanthus	2	Armagh.
Homalodus	2	,,
Isodius	1	Draperstown, Ireland.
Janassa	2	Derbyshire, Northumberland, &c.
Labodus	2	Armagh.
Lepracanthus	1	North Wales.
Lophodus	9	Yorkshire, Armagh.
Leptacanthus	2	Armagh, Derbyshire.
Lispacanthus	2	Armagh, Westmoreland.
Megalichthys	4?	Leeds, Glasgow.
Mesolepis	3	Staffordshire, &c.
Mesogomphus	1	Armagh.

Genera.	No. of Species.	Localities.
Mioganodus	1	Northumberland.
Microconodus	1	"
Mylax	1	Armagh.
Mitrodus	1	Northumberland
Mylacodus	2	Armagh.
Nematoptychius	1	Scotland.
Nemacanthus?	1	Armagh.
Ochlodus	1	"
Onchus	3	Armagh, Bristol.
Oracanthus	4	" "
Oreodus	1	" "
Orodus	14	Armagh, Bristol, Yorkshire.
Orognathus	1	Armagh.
Orthognathus	1	Northumberland.
Orthacanthus	1	Leeds, Scotland.
Ostracacanthus	1	Yorkshire.
Osteoplax	1	Ireland.
Petalodopsis	2	Northumberland, &c.
Petalodus	11	Armagh, Derbyshire, Bristol.
Petalorhynchus	2	Armagh.
Petrodus	1	Derbyshire.
Phanerosteon	1	Scotland.
Phoderacanthus	1	Bristol.
Physonemus	4	Armagh, Bristol.
Phricacanthus	1	Yorkshire.
Pinacodus	2	Armagh.
Phyllolepis	3	Scotland.
Platycanthus	1	Armagh.
Platysomus	5	Staffordshire, &c.
Pleuracanthus	10	Leeds, Dudley, &c.
Pleurodus	3	Lanarkshire, Recabore, Yorkshire.
Pleurogomphus	1	Armagh.
Pœcilodus	9	Armagh, Lanarkshire, Derbyshire.
Polyrhizodus	6	Armagh.
Priacanthus	1	Yorkshire.
Pristicladodus	2	Yorkshire, Westmoreland.
Pristodus	1	Yorkshire.
Psammodus	3	Armagh, Bristol, Oreton.
Psammosteus	2	Armagh, Bristol, &c.
Psephodus	1	Armagh, Westmoreland.
Pterodus	1	Northumberland.
Ptycacanthus	1	Near Edinburgh.
Ramphodus	1	Armagh.
Rhizodus	2	Near Edinburgh.
Rhizodopsis	2	Scotland, Staffordshire.
Rhadinichthys	5	Scotland, &c.
Rhymodus	2	Oreton, Shropshire.
Rhomboptychius?	1	Scotland.
Sandalodus	1	Oreton, Bristol.
Sphenacanthus	1	Near Edinburgh.
Stichacanthus	1	Tortworth, Gloucestershire.
Streblodus	3	Bristol, Hook Point, Armagh.
Sagenodus	1	Northumberland.
Strepsodus	2	Northumberland, Yorkshire, Scotland.
Tarrasius	1	Eskdale.
Tristychius	2	Lanarkshire, Fermanagh.
Tomodus	1	Bristol.

Genera.	No. of Species.	Localities.
Uronemus	2	Near Edinburgh.
Wardichthys	1	Scotland.
Xystrodus	4	Armagh.
127	353	

AMPHIBIA.

Anthracosaurus	1	Northumberland, &c.
Anthrakerpeton	1	Ireland.
Brachyscelis	1	,,
Discospondylus	1	,,
Dolichosoma	1	,,
Erpetocephalus	1	,,
Ichthyerpeton	1	,,
Lepterpeton	2	,,
Ophiderpeton	3	,,
Keraterpeton	1	,,
Leptognathosaurus	1	Northumberland.
Loxomma	1	Ireland.
Macrosaurus	1	Northumberland.
Megalocephalus	1	,,
Orthosaurus	1	,,
Pteroplax	1	,,
Parabatrachus	1	Scotland.
Megalerpeton	2	Ireland.
Urocorydylus	2	Northumberland, Ireland.
Pholidogaster	1	Scotland.
Pholiderpeton	1	Yorkshire.
21	26	

PART IV.

CHAPTER XXVII.

PERMIAN OR DYAS STRATA.

General Characters.—Throughout Europe many areas containing the Carboniferous rocks are also occupied by a peculiar group of strata, which are mostly, as a rule, unconformable to the underlying and older series. These strata are red sandstones, conglomerates, and breccias; in places, marls and limestones of a type essentially differing from other calcareous deposits. From their wide distribution and development in the Russian province of Perm, they were named "*Permian*" by Murchison, De Verneuil, and Keyserling. The name "*Poikilitic*" (variegated) was suggested by Conybeare, as an equivalent and comprehensive term for both series (Permian and Trias), which were originally included in the *New* Red Sandstone, the term used to distinguish all the divisions of the red rocks above the Carboniferous series, as contradistinguished from the *Old* Red Sandstone below. Palæontological evidence, however, is against this union, and more so in Germany than in Britain. The geological time represented by this great series of strata, intervening between the Carboniferous and the Jurassic systems, must have been enormous. In Germany they exhibit a well-marked grouping into two great series of deposits, and have hence received the name of "*Dyas*," or Twofold. On physical grounds Professor Sedgwick classed the Permian series with the Trias.

Permo-Carboniferous.—In North America the term "*Permo-Carboniferous*" has been adopted to denote the transitional beds at the top of the true Palæozoic series, *i.e.*, where no good line of subdivision can be drawn at the top of the Carboniferous system, or between that and the Permian. There are instances in Derbyshire, Lancashire, and Cheshire where an apparent gradation appears between the Coal-measures and the Permian sandstones.

Two distinct types of the Permian system have been determined in Europe—

A.	Dyas.	1st. A *lower group* of Red Sandstones and conglomerates, and, 2d. An *upper group*, consisting of limestones and dolomites.
B.	Russian or Permian.	In the Russian or Permian the beds are of similar character, but occur so interstratified as to present no distinct twofold petrographical subdivision.

Petrological Characters.—The prevailing rocks and materials composing the Permian series are red sandstones, conglomerates, and marls. The conglomerates are composed of crystalline and older Palæozoic rocks, mica schist, granite, quartzite, and various sandstones, &c. The argillaceous type consists of the marl slate or "*Kupferschiefer*" (a bituminous shale or marl, so called in Germany from its containing ores of copper). The limestone type (or Dyas) is the chief repository of the Permian invertebrate fauna; the dolomite, of the variety "*Rauchwacke*" is either cavernous or crystalline, or granular and crumbling (*Asche*), associated with bands of gypsum and rock-salt. In the south-west of Scotland the older part of the Permian system contains contemporaneous eruptive masses, among which occur *Melaphyre*, *Porphyrite*, and *Quartz-Porphyry*. Coarse breccias occur in the lowest portion, composed of angular fragments of older rocks; and the beds at "Corncockle Muir," in Annandale, afford, or have exhibited, the footprints of Labyrinthodontia.

Probably of Fresh-water Origin.—The Permian rocks, from their lithological and mineral characters, were evidently deposited in isolated basins, probably of fresh water, and more or less shut out from the sea. The water in these basins must have undergone extreme concentration and chemical precipitation, so as to have resulted in the accumulation now presented of dolomites, saliferous clays, rock-salt, gypsum, and anhydrite. Changes in the physical geography of the Carboniferous rocks probably excluded the sea from that region wherein the Permians were being deposited, extensive lagoons occupying the area; these, as the Carboniferous land became depressed, spread over the older barriers, the result being the overlapping or unconformity of the Permian rocks to the Carboniferous or older rocks still.

Types.—The Lower Permian Rocks of the western and central parts of England may be arranged under two distinct types,—one represented by the strata or deposits at *Enville* in Shropshire, and the other by the sandstone of *Collyhurst* near Manchester.

A. The *Salopian type* embraces the whole of the Permian rocks in Shropshire, Staffordshire, and Warwickshire.

B. The *Lancashire type* is illustrated by the rocks of this formation, as developed at Stockport in Cheshire, in South Lancashire, and in Cumberland, &c.

I. The rocks of the *Salopian type* attain a thickness of 1500 feet, and comprise—

a. Red and purple sandstones and marls; breccias, calcareous conglomerates, marls, and sandstones; purple, red, brown, and white sandstones, often calcareous.

II. The rocks of the *Lancashire type* include—

b. Red marls, with numerous beds or bands of fossiliferous limestone, worked for lime, 130 feet thick. (These western beds without doubt represent the *magnesian limestones of Yorkshire and Durham* (Dyas type), on the eastern side of the Pennine chain.)

c. Bright red and variegated sandstone, about 1500 feet thick.

Lower Sandstones.—The red rocks comprising this sub-division attained their greatest development in the Vale of Eden, where they

are brick-red sandstones, and calcareous conglomerates or breccias, derived from the waste of the Carboniferous limestones.[1] These sandstones and marls range round the whole of the north of Cumberland, from Kirkby-Stephen to Longport, north of Carlisle, and thence to Maryport, covering up unconformably much of the Whitehaven coal-field and Carboniferous limestone. They border the seashore from St. Bee's Head to the estuary of the Duddon, and occur further south at Walney Island. They extend also across the Solway into the valleys of the Nith and Annan in the south of Scotland. The researches of Geikie have shown that, in the "basin of the river Nith, and also in Ayrshire, numerous volcanic vents, and sheets of porphyrite and tuff, are associated with these Red Permian Sandstones, determining a volcanic district of *Permian age*. The vents rise through coal-measures as well as more ancient rocks."

The only organic remains in these north-western Permian sandstones are those of plants, indicative of terrestrial surfaces. Such are *Lepidodendron dilatatum*, *Calamites*, *Sphænopteris*, *Alethopteris*, *Ullmannia*, *Cardiocarpum*, and probably a marine alga, *Caulerpites*, with fragments of coniferous wood.

The section at St. Bee's Head shows the following sub-divisions:—

	Feet.
Upper Permian, or St. Bee's sandstone	—
Red and green marls, with gypsum	30
Yellow magnesian limestone, with casts of fossils	11
Breccia	3
Whitehaven sandstone (coal-measures or Permian?)	

The two contrasted types of the European Permian system are represented in England, one on either side of the island. That on the eastern side from South Shields, on the coast of Northumberland, along the border of the coal-fields of Yorkshire and Nottinghamshire, to the plains of the Trent west of Mansfield, exhibits the true "Dyas," *Magnesian limestone*, or German type. These limestones and the Marl Slate form the main feature of the eastern type. To what extent they may pass westwards under the Triassic or Jurassic rocks of Yorkshire and Nottinghamshire we know not.

On the western side of the Pennine chain the true Permian or Russian facies occur. The following tabular arrangement exhibits the two types of rocks:—

	West of England (Permian or Russian Type).	East of England (Dyas or German Type).
(*a.*) Red Sandstones, clays, and gypsum	600 feet.	50–100 feet.
(*b.*) Magnesian Limestone (*c.*) Marl slate	10–39 „	600 „
(*d.*) Lower red and variegated sandstone, reddish-brown and purple sandstones and marls, with calcareous conglomerates and breccias	3000 „	100–250 „
		—(*Geikie.*)

[1] This breccia is locally termed "*Brockram.*"

Magnesian Limestone—Dolomitic Limestone or Dolomite.

This, the chief fossil group of the Permian system, is usually of a yellowish colour, seldom red; at the lower part occasional thin limestone bands (marl slate) occur, succeeded by an upper thick mass of Magnesian Limestone (Dolomite), the chief feature in the Permian (Dyas) of the East of England above noticed. The Magnesian Limestone holds a persistent place or zone down the north-east of England from South Shields to Nottingham. The bright red and variegated sandstones of Lancashire and Cheshire and thin marls represent these eastern beds in time, but are devoid of the comparatively rich fauna they contain.

Fauna and Flora.—The Magnesian Limestones have yielded a fauna of 92 genera and 203 species, and a well-marked flora, comprising 18 genera and 26 species; the whole known fossil contents being 110 genera and 229 species, poor in all groups as contrasted with the preceding Carboniferous and other older systems. Numerically the genera and species are:—*Plantæ*, 18 genera and 26 species, 18 of which belong to the Rothliegende, and 6 to the marl slates, to the Middle and Upper limestones 1 species each; *Protozoa*, 4 genera and 5 species; *Rhizopoda*, 5 genera and 12 species; *Cœlenterata*, 3 genera and 5 species; *Echinodermata*, 2 genera and 2 species; *Crustacea*, 4 genera and 29 species; *Polyzoa*, 6 genera and 6 species; *Brachiopoda*, 15 genera and 36 species; *Pelecypoda*, 20 genera and 37 species; *Gasteropoda*, 11 genera and 26 species; *Cephalopoda*, 1 genus and 1 species; *Pisces*, 8 genera and 23 species; *Reptilia*, 9 genera and 17 species. The most characteristic fossils of the Permian are given below.

Characteristic Fossils.—

PLANTÆ.—*Alethopteris Göpperti, Walchia piniformis, Cyclopteris dilatata, Neuropteris Huttonia*, and *Sphænopteris latifolia.*
FORAMINIFERA.—*Dentalina communis* and *Textularia cuneiformis.*
CŒLENTERATA.—*Polycœlia profunda.*
ECHINODERMATA.—*Archæocidaris Verneuliana.*
CRUSTACEA.—*Prosoponiscus problematicus, Kirkbya permiana.*
POLYZOA.—*Fenestella retiformis* and *Acanthocladia anceps.*
BRACHIOPODA.—*Productus horridus, Camarophoria Schlotheimi, Strophalosia Goldfussi, Lingula Credneri*, and *Spirifera permiana.*
PELECYPODA.—*Gervillia antiqua, Lima permiana, Avicula speluncaria, Arca Kingiana, Allorisma elegans, Schizodus dubius, Pleurophorus costatus, Cardiomorpha Pallasi.*
GASTEROPODA.—*Pleurotomaria antrina, Turbo helicinus, Turbonilla Phillipsii.*
CEPHALOPODA.—*Nautilus Freieslebani.*
PISCES.—*Acrolepis Sedgwickii, Coelacanthus caudalis, Palæoniscus elegans, P. Freieslebani, P. comptus.*
REPTILIA.—*Chelichnis ambiguus, Dasyceps Bucklandi, Proterosaurus Speneri*, and *Lepidotosaurus Duffii.*

One hundred and fifty of the two hundred and five species occur in the Magnesian Limestone, the remainder in the marl, slate, and Rothliegende.

The Dolomite Limestone of Marsden, near Sunderland, is flexible. The thickness of the Magnesian Limestones in their type localities (Durham and Pontefract) is about 300 feet.[1] The Lower Magnesian Limestone near Tadcaster contains Chert, which is termed *Calliard* or *Galliard.*

German Dyas.—The Dyas type of the system attains a great development in Europe along the flank of the *Harz Mountains, Saxony, Bavaria, Thuringia, Bohemia,* &c. The following subdivisions may be received as showing the grouping of the Permian rocks on the south side of the Harz, or the Upper Zechstein, and the Rothliegende groups :—

Zechstein Group.	"Anhydrite, gypsum, rock-salt, marl, dolomite, fetid shale, and limestone. The amorphous gypsum is the chief member of this group; the limestone is sometimes full of bitumen."
	"Crystalline, granular (Rauchwacke), and fine sandy (asche) dolomite 6 to 65 feet."
	"Zechstein—an argillaceous, thin-bedded, compact limestone, 15 to 30 (sometimes 90) feet thick."
	"Kupferschiefer—black bituminous shale, 2 feet thick."
	"Zechstein—conglomerate and calcareous sandstone."
Rothliegende Group.[2]	"Upper.—Conglomerates (quartz-porphyry conglomerate) and sandstone with associated melaphyres and tuffs."
	"Middle.—Red clay, shales, and fine shaly sandstones, with bands of quartz conglomerate and earthy limestone; melaphyre and porphyritic masses intercalated."
	"Lower.—Shaly sandstones, shales (with bituminous bands), and conglomerates." —(*A. Geikie.*)

Sequence of Permian Strata.—With respect to the order of succession, the Permian strata, like those of every other system, present local differences and irregularities. In the great undisturbed region of Central Russia, the Permian system consists of three members, viz. :—

1. Sandstones and conglomerates and grits; limestones in various courses with characteristic fossils, associated with marls and gypsum, the marls occasionally containing in places plants and seams of impure coal.
2. Red sands, with copper ore and many plants.
3. Conglomerate and sandstone with plants and fossil reptiles.

In the North of England (Durham and Yorkshire), where the Permian beds are composed chiefly of Red Sandstone and grits, of Magnesian Limestones and gypseous marls and laminated calcareous flagstones, the succession is as follows :—

[1] In some of the great chemical works on the Tyne, the Dolomites of the northern counties are used for the production of carbonate of magnesia; they are also treated with sulphuric acid for the purpose of obtaining "sulphate of magnesia" (Epsom salts).

[2] The name "Rothliegende" or "Roth-todt-liegende," red-layer or "Red Dead-layer," was applied to these beds by German miners, because their ores, disappearing in the red rocks below the copper-bearing Kupferschiefer, became "dead," or non-metalliferous.

Magnesian Limestone Group.	*Laminated Limestone*, with layers of coloured marls, as at Knottingly, Doncaster, &c. *Gypseous Marls*—Red, bluish, and mottled. *Magnesian Limestone*—Yellow and white, of various texture and structure in some parts, as at Tynemouth, brecciated, or made up of fragmentary masses. *Marl Slates*—Laminated, impure, calcareous flagstones, of soft argillaceous or sandy nature.
Red Sandstone Group.	*Red Sandstone*, with red and purple marls and a few micaceous beds; the grits are sometimes white or yellow and pebbly. When conformable, this sandstone occasionally passes into the coal-measures on which it rests.

The following is a more extended tabulation of the two groups :—

TABLE XXXVIII.—*Types of Permian Rocks.*

Mesozoic or Triassic (Bunter and Keuper).	4. Series of coloured marls.	Purple-coloured marls below the lias. Attenuation of red and bluish-white marls, with layers and nodules of gypsum. Thin layers of argillo-calcareous stone. Red and bluish marls, with gypsum and beds of rock-salt.
	3. Variegated red and white sandstone.	Red and white sandstone, mostly fine-grained, and often impregnated with salt. Red conglomerate, full of pebbles of older rocks.
Palæozoic or Primary (Permian).	2. Magnesian limestone.	Red and white marls. Thin-bedded compact limestone, with very little magnesia and few organic remains. Red and white marls and gypsum. White, yellow, or reddish magnesian limestones, in thick beds, crystallised, compact, or earthy; often full of sparry cavities, and containing marine remains. Marl slate in thin layers, occasionally enclosing fishes and reptiles.
	1. Yellow or purple sand, and sandstone and marl.	An extremely variable series of sandstones, sands, and clays of various colours, irregular in thickness, with much local diversity of character. Plants like those of the coal-measures.

From this table we perceive the limits of the Permian and Triassic systems (as developed in England). The term *Permian* is used through custom, and from its general acceptance, though the name "*Dyas*" (or Twofold group) was earlier in use by German geologists, and invented to harmonise with the term *Trias*, their *Dyas* and *Trias* being the equivalents of our *Permian* and *Triassic*.

Correlation of the Permian Rocks.

Triassic Group.—From the fact of the lower members containing fossils more or less allied to the Carboniferous types, and the upper members possessing those more or less allied to Jurassic forms, it has been proposed to separate them into two distinct

systems—the Permian and the Triassic. Regarding the triple group of Germany as typical of the upper series, we have therefore the following synopsis :—

	Germany.	England.
Trias.	Keuper.	Saliferous marls and grits.
	Muschelkalk.	(*Wanting*).
	Bunter Sandstein.	Variegated sandstones.
Permian.	Lower Bunter.	Gypseous marls and grits.
	Zechstein.	Magnesian limestone.
	Kupferschiefer.	Marl slate.
	Rothliegende.	Red sandstone.

Saxon Permians.—In the Alps the Permian strata are scarcely, if at all, represented. It is to the middle of Germany, in Thüringia, in Saxony, and in the country which lies to the south of the Harz Mountains, that we must look for their typical development.

The gradation from the Dyas upwards into the Trias in Germany is most complete, and the palæontological distinction most pronounced. Credner gives the following classification of the whole series.

Trias.	3. KEUPER, a formation of marls, sandstones, and gypsum, with land-plant remains.
	2. MUSCHELKALK, a calcareous formation, with remains of marine fauna.
	1. BUNTER SANDSTEIN, a shore formation, with land-plant remains.
Dyas.	2. ZECHSTEIN group, a formation of limestone, dolomite, and gypsum, with remains of marine fauna ("Kupferschiefer") as a base.
	1. ROTH-LIEGENDE, a formation of conglomerates and sandstones, with remains of a land flora.

The Permians of Russia do not admit of any exact parallelism petrographically with the Dyas of Germany, for there is in them no recognisable division into an "*upper* limestone-dolomite-gypsum-formation," such as occurs in the Zechstein, and a "*lower* sandstone-conglomerate-marl-formation with the remains of land-plants, such as is found in the Rothliegende." On the contrary, the limestones and dolomites of the Russian series are repeated over and over again through nearly its whole range.

The upper members of the Permian series (Magnesian Limestone and its associated marls) of the northern counties are wanting in the Midlands, south of the Trent Valley. This is also the case in Germany; "as we proceed south, the Zechstein formation vanishes."[1]

Southern Germany.—In Southern Germany the lower formation of the Dyas is widely distributed; it extends from the Thüringerwald southwards along the south-west slopes of the Fichtelgebirge and the Böhmerwald into Bavaria. The shales contain numerous nodules of clay ironstone with remains of *Amblypterus macropterus* and *Archegosaurus Dechani* Goldf.

Professor Harkness[2] in 1862 described six different sections, in four of which the rocks classed as Permian rest upon Carboniferous

[1] Rev. A. Irving, Geol. Mag., Dec. II., vol. ix. p. 220.
[2] Jour. Geol. Soc., II., vol. xviii., 1862.

strata, and two upon rocks of Silurian age. Intrusive igneous rocks occur in these deposits as they do in the Rothliegende of Germany.

Conditions of Deposition.—Taking the whole composition, succession, and organic remains of both systems, they indicate a period of shallow seas, supercharged with the saline matter of muddy estuaries and lagoons, a period of frequent depressions and elevations, and peculiar climatic influences. During this age many forms of life disappeared, and were replaced by others of a different type and order; hence the Permian group is regarded as Palæozoic, and the Triassic as Mesozoic.

The sequence of conditions in Upper Palæozoic times has been well generalised by Credner in tabular form, and we transcribe it, on account of its value, as rendered by Mr. Irving:—[1]

TABLE XXXIX.—*Sequence of Conditions in Upper Palæozoic Strata.*

5. Deep sea.	Marine formations.	Limestone.	Marine animal remains.	Zechstein Rothliegendes.	Dyas.
4. Subsidence under the sea.	Shore formations.	Conglomerates and sandstones.			
General Unconformity.					
3. Stationary condition broken by insignificant oscillations.	Fresh-water and marsh formations broken by shore and shallow sea formations.	Coal-bearing strata.	Land plants.	Coal-bearing Rothliegendes and productive coal-measures.	Carboniferous.
2. Elevation above the sea.	Shore formations.	Conglomerates and sandstones, limestones.		Sandstones without coal-seams, culm, Carboniferous limestone.	
1. Deep sea.	Marine formations.		Marine animal remains.		

British Development.—Notwithstanding great physical changes in the condition of the Devonian and Carboniferous series, the fauna and flora of the succeeding Permian epoch, although consisting chiefly of new species, were, nevertheless, generically connected with the preceding or Carboniferous, whilst they are totally dissimilar to those of

[1] Credner: "Elemente der Geologie," p. 475, 1870; also Geol. Mag. Dec. II., vol. ix. p. 273.

the succeeding Trias. At the close of the Carboniferous series, the strata which succeeded were called (in England) Lower New Red Sandstone, marl slate, magnesian limestone, &c.

In the north of England the various deposits which are now united in one group were ably described by Professor Sedgwick,[1] who clearly showed their relation to the German rocks of the same age. Professor Phillips[2] first suggested that the "*magnesian limestone*," through its fossils, should be classed with the Palæozoic rocks. Subsequently the fossil remains of this limestone have been illustrated by Professor W. King,[3] and Messrs. Howse[4] and Kirkby.[5]

The Permian rocks of Britain, where most clearly developed, consist in ascending order of—

1. Lower red and yellow sandstones and conglomerates, the equivalents of the Rothliegende.
2. The marl slate and magnesian limestone, the equivalents of the Kupferschiefer and Zechstein.

The best types, particularly of the calcareous or central portion, occur in the counties of Durham, York, and Nottingham.[6] The Lower Sandstone is well seen at Clacksheugh near Sunderland, on the left bank of the Wear. In many sections the limestone is united to the sandstone by the marl slate, which is probably the equivalent of the Kupfer-schiefer of Germany. This marl contains about 30 species of fossils, many genera of fish (*Palæoniscus* 3 species, *Platysomus* 2, *Pygopterus* 2, *Cœlacanthus* 2, *Acrolepis* 1, &c.), and plant remains (6 species).

The overlying yellow magnesian limestone is finely exposed in the coast section from Sunderland to Hartlepool. *Schizodus obscurus* characterises this rock through Yorkshire, and is conspicuous also between Doncaster and Nottingham. Sections traced from west to east upon the edge of the Yorkshire coal-basin give the following succession, reading upwards :—

1. A thin band of Lower Red Sandstone.
2. A great mass of thick-bedded magnesian limestone.
3. A zone of red marl with gypsum.
4. Thin-bedded limestone (trace of magnesia).
5. Red sands and marls, which form the summit of the whole group.

On the banks of the Nid, near Knaresborough, the Lower Red Sandstone is conspicuous, passing into an angular and sub-angular quartzose conglomerate, undistinguishable from the Rothliegende of Germany. South of Pontefract these Lower Sandstones begin to thin out, expiring altogether near Nottingham, where the magnesian limestone rests at once upon the coal-measures. On the western side or flank of the Pennine chain, this lower division is greatly expanded.

[1] Trans. Geol. Soc., 2d ser., vol. ii.
[2] Treatise on Geology, p. 189.
[3] Monog. Perm. Fossil. Pal. Soc., 1856.
[4] Ann. Nat. Hist., 2d ser., vol. xvii.
[5] Q. Jour. Geol. Soc., &c.
[6] Sedgwick on the Magnesian Limestone, Trans. Geol. Soc., 2d ser., vol. iii.

Professor King, in his fine monograph of the Permian fossils, clearly shows that the fossiliferous beds of compact limestone represent *the Lower*, and the brecciated and concretionary limestones of Durham *the Upper* Zechstein of Germany, with its overlying beds of Dolomite, Rauchwacke, and Stinkstein.[1] At Manchester we no longer trace the magnesian limestone as a separate mass. Its place is taken by red marl and shale, with thin limestone, which yield the genera *Schizodus*, *Avicula* (*Monotis*), *Turbo*, and *Rissoa*, &c.

In the Warwickshire area the Permian strata are generally *conformable to the coal-measures*, and possess great uniformity of character throughout. The Palæontological evidence afforded is meagre, hardly sufficient to separate them from the Carboniferous series.

The valley of the Eden in Westmoreland contains a great thickness of Permian sandstones. *The lowest* beds consist of the brick-red Penrith sandstone, which is surmounted by calcareous breccias. To the north of St. Bee's, or the Permians of that area, no Dyas, Magnesian Limestone, or Zechstein is known, and the Permian rocks as they range into Scotland become one great mass of sandstone, overlying the south-western coal-measures.

Associated Igneous Rocks.—Professor A. Geikie has ascertained that below the lowest Permian of Ayrshire there are beds of contemporaneous igneous rocks, a fact of great physical importance and interest, showing that in parts of Britain (as throughout Central Germany) volcanic action of great intensity was frequent during and after the deposition of the Lower Permian period, as illustrated by the manner in which intrusive and eruptive greenstone (Dolerite) traverses and penetrates the Permian trap rocks, and also by the evidence presented by necks of volcanic agglomerates of Permian age and felspathic amygdaloidal trap with interbedded brick-red Permian sandstones, the occurrence of trap tuffs, &c. &c. The basin of the Ayr, which occupies an area six miles long by five wide, is completely encircled by a ring of trap tuffs, amygdaloidal traps, and red sandstones, which lie upon the upper part of the coal-measures, forming the base of the Permian series.

In their range through the Midland Counties the Permian rocks contain many plants in a highly silicified state, corresponding to stems occurring in the Rothliegende of Germany. (*See list of plants under this heading in General List.*)

Typical Local Development.—The best fossiliferous British types of the Permian group are only to be studied in those counties which lie to the north of the Trent. Thus, in the English northern counties it is only in Nottinghamshire, Yorkshire, and Durham that we meet with the true Magnesian Limestone or Zechstein and its characteristic fossils; whilst in Worcestershire, Warwickshire, Shropshire, and Lancashire the entire group is to be paralleled with that of Southern Germany and Russia through the Red Sandstone, marls, conglomerates, and breccias, with traces only of calcareous matter.

[1] See King: "Mono. Permian Fossils," Trans. Palæontological Soc., 1850.

CHAPTER XXVIII.

PALÆONTOLOGY OF THE PERMIAN ROCKS.

THE fauna and flora of the Permian strata are essentially Palæozoic.

I. *Flora.*—In Britain the flora is a scanty one, few species occurring in their respective genera—18 genera and 26 species complete the known number. (*See General List.*) To what degree it really differs from the underlying coal-measures or the Carboniferous group is not known; some species are identical with coal plants. Enumerations of foreign Permian strata contain a much larger flora, arising from more continued research.[1] Professor Göppert has enumerated from the Rothliegende and Kupferschiefer of Germany and the Permian rock of Russia no less than 182 species, of which 169 occur in the lowest member or Rothliegende alone. Göppert, Brongniart, and Morris conclude that this flora, whether composed of the plants of the Rothliegende, or the Zechstein and overlying beds in Russia, differs from all other fossil floras, and strikingly marks the close of the Palæozoic times.

II. *Fauna.*—The chief fossils bear a close resemblance to those of the Carboniferous series. Nearly 400 species are known, and out of this number 229 are British.

POLYZOA are all of Palæozoic types, as illustrated by species of *Synocladia*, *Fenestella*, *Thamniscus*, *Phyllopora*, and *Acanthocladia*.

ACTINOZOA through *Polycœlia* (*Calophyllum*), *Alveolites*, and *Monticulipora*.

ECHINODERMATA are represented by only two species, *Archæocidaris Verneuiliana*, and *Cyathocrinus ramosus*, both Palæozoic genera.

BRACHIOPODA.—The genera are without exception of older types, and 6 species out of the known 21 pass up from the Carboniferous below or connect the two groups; these include *Camarophoria globulina*, *Lingula credneri*, and *Spiriferina cristata*.

Characteristic Species.—The essentially Permian species are *Productus horridus*, *P. latirostratus*, *Camarophoria Humbletonensis*, *C. schlotheimia*, *Spirifera permiana*, *S. clannyana*, *S. alata*, *Strophalosia goldfussi*, and *Terebratula elongata*.

It should be remembered that of the 36 species of British Permian Brachiopoda, 15 occur in the same strata in Germany, whilst among them there are 7 species which extend their range even to the north-eastern extremity of European Russia.

Pelecypoda.—Among the Pelecypoda or bivalve shells the following species may be considered as characteristic:—*Allorisma elegans*,

[1] The sandstones of Lodève yield the following genera of ferns:—*Sphænopteris*, *Pecopteris*, *Neuropteris*, *Alethopteris*, and *Callipteris*, besides *Annularia* and many conifers of the genus *Walchia* ("Russia in Europe," vol. i. p. 219). The Rothliegende near Zwickau in Saxony have yielded 60 species, mostly Permian. Large silicified stems of tree ferns (*Psaronites*) abound in Germany.

Pleurophorus costatus, *Schizodus obscurus*, *Myoconcha costata*, and *Myalina Housmannii*. These, out of the 37 known British species, may be regarded as important forms. Not more than 80 species in all are known to Europe generally. This diminution from the preceding Carboniferous, which numbered 50 genera and 386 species, shows how great were the changes in the physical conditions and geography of the Carboniferous areas, through downward subterranean movements. The wide geographical distribution of some Permian species (several of which are almost ubiquitous) testifies to the lengthened period in its sedimentation. *Monotis speluncaria* occurs in the province of Archangel, in Germany, England, and the United States; others, like the Brachiopoda, are found far and wide.

Gasteropoda.—This large group in the Carboniferous rocks (34 genera and 225 species) dwindled down to 11 genera and 26 species in the British Permian seas, and we know of no form of Pelecypoda or Gasteropoda out of the 611 species in the Carboniferous rocks that passed to the Permian.

Cephalopoda.—More significant still is the class Cephalopoda. Every species of the known 154 Carboniferous species either died out or migrated, for succeeding history records them not. The *Orthocerata*, *Goniatites*, and *Nautili* have but one known representative (*Nautilus Frieslebani*) in the Permian. The Permian strata of the United States and the German Zechsteins have yielded about 10 species of *Orthoceras* and *Cyrtoceras*.

Fishes.—The fossil fishes, in the British Permian rocks, comprise 8 genera and 23 species—viz., *Acrolepis* 3 species, *Cœlacanthus* 2, *Dorypterus* 1, *Gyracanthus* 1, *Gyropristis* 1, *Palœoniscus* 11, *Platysomus* 2, and *Pygopterus* 2 species. Twelve of these occur in the marl slate, 7 in the Lower Limestone, 2 in the Middle, and 5 in the Upper Limestone. No species are common to the Permian and Carboniferous rocks.

Amphibia.—Amphibian life must have been abundant in Permian times, many of the sandstones being covered with footprints, which are assigned to the order Labyrinthodontia. The remains of *Lepidosaurus*, *Zygosaurus*, &c., have been met with, either as occasional bones or skulls. Dr. Anton Fritsch of Prague has discovered in the Permian basins of Pilsen and Rakowitz, in Bohemia, no less than 43 species of amphibians:—*Branchiosaurus*, *Sparodus*, *Hylonimus*, *Dawsonia*, *Melanerpeton*, *Dolichosoma*, *Ophiderpeton*, and *Palæosiron*, have already been described.[1] Corresponding strata in Autun, in Central France, have yielded additional genera, described by Gaudry[2]—*Actinodon*, *Protriton*, a new genus of *Batrachia*, *Pleuroneura*, and a form (*Euchirosaurus*), larger and more highly organised than any yet known from the Palæozoic rocks of France. Two species of Proterosaurus (*P. speneri* and *P. Huxleyi*), the earliest known European Lacertilian

[1] A. Fritsch: "Fauna der Gaskohle und der Kalksteine der Permformation Böhmens," Prag. 1881–2.

[2] Bull. Soc. Géol. France, vol. vii. (3 sér.), p. 62; Delaford, Bull. Soc. Géol. France; vol. iv. (3 sér.), p. 727.

reptilia, occur in the marl slates of Durham, and in the corresponding Kupferschiefer in Germany. Seven genera and 14 species occur in the Rothliegende.

Correlation of the British and German Permian Remains.

As we have seen, neither the fauna nor flora of the British Permian or Triassic rocks could be regarded as large or important. The Permian partakes largely of the Carboniferous type, of which it is the closing scene. Only 110 genera and 229 species are known in the British Permian series, and 107 genera and 199 species in the Triassic group, *i.e.*, including the Rhætic.

The flora of the Dyas is closely allied to that of the Carboniferous, and represents the last remains and traces of a vanishing epoch. The plant remains are mostly confined to the Rothliegende. Of the 18 genera and 26 species known, no less than 12 genera and 18 species belong to this horizon; 16 are confined to it, while 5 genera and 6 species are met with in the marl slate. The two species occurring both in the Rothliegende and marl slate are *Ullmania Brownii* and *Ullmannia Selagmoides*. Though poor in forms of life, both the flora and fauna have a definite Palæozoic character, closely allied to that of Carboniferous times. Of the 16 genera that occur 14 are Carboniferous, and the following 7 species pass up from that series or occur in both:—*Calamites arenaceus*, *Cyclopteris dilatata*, *Lepidodendron dilatatum*, *Neuropteris gigantea*, *Sphœnopteris latifolia*, *Trigonocarpum Nöggerathi*, and *Sigillaria reniformis*.

No less than 60 species occur in the Permian rocks of Saxony. Upon the whole, the plants of the marl slate (base of the Magnesian Limestone in the North of England) differ considerably from those of the coal period, and the plants of the Rothliegende of Germany show, as in Britain, a close generic affinity with Carboniferous species. They include forms of *Calamites* (*C. gigas*), *Asterophyllites*, *Sphenopteris*, *Alethopteris*, *Neuropteris*, and *Odontopteris*, with also well-preserved silicified stems of tree-ferns (*Psaronius*[1] and *Tubicaulis*). The conifer Walchia (*W. piniformis*) is specially characteristic both in Britain and Germany. According to M. Grand' Eury, no less than 50 species of plants are common to the two floras. The following may be specially mentioned:—

Calamites Suckowii, *C. approximatus*, *Asterophyllites equisetiformis*, *A. rigidus*, *Pecopteris elegans*, *Odontopteris schlotheimi*, *Stigmaria ficoides*, *Cordaites borassifolius*, &c. The most characteristic plants throughout the German Permian groups are *Odontopteris obtusiloba*. *Callipteris conferta*, *Walchia piniformis*, and *Calamites gigas*. No one can doubt that the Permian flora presents many points of resemblance to and affinity with the Carboniferous.[2]

The Zechstein group is characterised by a fauna corresponding to that of the Magnesian Limestone of England. Among the many fossils

[1] Twenty-four species are described by Göppert, "Ueber die Flora der Permischen Formation," 1864–5.

[2] Göppert: "Ueber die fossile Flora, der silurischen, der devonischen, und unteren Kohlenformation oder sogenannten Uebergangsgebirges." 4to. 1859.

are *Productus horridus, Spirifera undulata, Schizodus obscurus, Strophalasia Goldfussii*, and *Fenestella retiformis*. That the fauna of the Dyas was much poorer than that of the Carboniferous, we have ample evidence; with the exception of a few reptiles and fishes, it is limited to the marine portion of the series. The Cephalopoda have decreased to two species, and this is the case also in *Russia* and *America*. The fishes are mostly small ganoids, vastly abundant individually. The development of Reptilia, by the appearance of higher types, was an important advance. The Ammonitidæ, through *Ceratites*, commenced their well-known career, passing away only with the close of the Cretaceous period. The fishes of the Trias are partly heterocercal, small-scaled ganoids. True osseous fishes (Teleostei) do not yet exist, and the remains of the oldest known mammal belong to the highest stage of the Trias. We have already given on p. 309 the characteristic species of the British Permians.

TABLE XL.—*Stratigraphical Sequence and Geographical Distribution of the British Permian Strata.*

		Durham.	Yorkshire.
Bunter Schiefer = New Red Sandstone.			
Upper	Upper limestone (*crystalline limestone*, King).	1. Yellow, concretionary, and crystalline limestone; *loc.*—Marsden, Fulwell, Roker, Hartlepool, Cleadon Hills, Hickleton—250 feet.	Brotherton limestone, and Lower red marl and gypsum; *loc.*—Brotherton, Knottingly, Tickhill, &c.
Middle	Middle limestone (*shell limestone*, King).	2. Shale and cellular limestone = fossiliferous and pseudo-brecciated limestone (King); *loc.*—Tunstall, Humbledon, Rhyope, Galleys Gill, Down Hill, Claxheugh, Dalton, Hylton North, Castle Eden, &c.—150 feet.	Small-grained dolomite; *loc.*—Vale of Went, Lound Hill, Cusworth, Levit Hogg, Roche Abbey, Warmsworth.
Lower	Lower Limestone (*compact limestone*, King).	3. Compact limestone; *loc.*—Pellion, Whiteley, Penshar, Houghton, Ferry Hill, Thickley, Midderidge, Garmundsway, Millfield, Whiteley—200 feet.	Lower limestone of Pontefract; *loc.*—Wentbridge, Hampole, Emsall, Brodsworth, Conisborough, Micklebring.
	Kupfer-schiefer (*marl-slate*, King).	4. Marl slate; *loc.*—Claxheugh, Down Hill, Midderidge, Ferry Hill, Thickley, Houghton, Whiteley, Cullercoats, W. Bolden, Brassleton, Thrislington.	
	Rothliegende.	5. Lower Red and Yellow Sandstone; *loc.*—Tynemouth, Claxheugh, Hylton, Ferry Hill, Westoe.	Lower Red, Yellow, and Variegated Sandstone of Pontefract; *loc.*—Hickleton, Cadeby.

TABLE XLI.—*Numerical Distribution of the Permian Fauna.*

	Genera.	Species.	Rothliegende.	Marl Slate.	Lower Limestone.	Middle Limestone.	Upper Limestone.	Pass up.
Plantæ	18	26	$\frac{12}{13}$	$\frac{5}{7}$	...	$\frac{1}{4}$	$\frac{2}{3}$	None pass higher.
Spongida	4	5	$\frac{1}{1}$	$\frac{1}{1}$	...	$\frac{1}{4}$	...	
Rhizopoda	5	12	...	...	...	$\frac{1}{4}$	$\frac{2}{3}$	
Cœlenterata	3	5	...	...	$\frac{1}{2}$	$\frac{1}{4}$	...	
Echinodermata	2	2	$\frac{1}{2}$	...	...	$\frac{1}{4}$	...	
Annelida	3	3	...	...	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{2}{3}$	
Crustacea	4	29	...	$\frac{1}{7}$	$\frac{1}{7}$	$\frac{1}{10}$	$\frac{1}{3}$	
Polyzoa	6	6	$\frac{1}{2}$	...	...	$\frac{1}{4}$	$\frac{1}{3}$	
Brachiopoda	15	36	$\frac{1}{2}$	$\frac{2}{7}$	$\frac{1}{7}$	$\frac{1}{10}$	$\frac{1}{3}$	
Monomyaria	6	13	...	...	$\frac{1}{7}$	$\frac{1}{8}$	$\frac{1}{3}$	
Dimyaria	14	24	...	$\frac{2}{7}$	$\frac{1}{7}$	$\frac{1}{10}$	$\frac{1}{3}$	
Gasteropoda	11	26	...	$\frac{1}{7}$	..	$\frac{1}{10}$	$\frac{1}{3}$	
Pteropoda	1	1	...	...	...	$\frac{1}{4}$	...	
Cephalopoda	1	1	...	$\frac{1}{7}$	$\frac{1}{7}$	$\frac{1}{4}$	$\frac{1}{3}$	
Pisces	8	23	$\frac{2}{3}$	$\frac{1}{14}$	$\frac{1}{7}$	...	...	
Reptilia	9	17	$\frac{7}{14}$	$\frac{1}{7}$	...	...	...	
	110	229	$\frac{15}{65}$	$\frac{21}{70}$	$\frac{11}{77}$	$\frac{67}{196}$	$\frac{26}{43}$	

TABLE XLII.—*Organic Remains of the Permian Strata.*[1]

PLANTÆ.

Genera.	No. of Species.	Localities.
Alethopteris	1	Durham.
Brecia	1	
Calamites	2	Durham.
Chondrites	2	Manchester.
Cardiocarpon	1	
Cyclocarpon	3	
Cyclopteris	1	
Caulerpites ?	1	Durham.
Filograna	1	
Neuropteris	2	
Lepidodendron	1	
Pinites	1	
Sigillaria ?	1	
Sphænopteris	3	
Trigonocarpum	1	
Ullmania	2	
Walchia	1	
Voltzia ?	1	Northumberland.
18	26	

[1] For some characteristic fossils, see Plate XVI.

SUB-KINGDOM—PROTOZOA.

Genera.	No. of Species.	Localities.
Scyphia	1	Durham.
Mammillopora	1	,,
Tragos	2	,,
Bothroconis	1	,,
4	5	

Class—RHIZOPODA.

Dentalina	4	Durham.
Miliola	1	
Spirilina	2	Durham.
Textilaria	4	,,
Trochamina	1	
5	12	

SUB-KINGDOM—CŒLENTERATA.

Class—ACTINOZOA.

Alveolites . .	1
Monticulipora	2
Polycœlia	2
3	5

SUB-KINGDOM—ANNULOIDA.

Class—ECHINODERMATA.

Cyathocrinus	1	Durham, Northumberland.
Archæocidaris	1	Durham.
2	2	

SUB-KINGDOM—ANNULOSA.

Class—ANNELIDA.

Spirorbis	1	Durham, Northumberland.
Vermilia	1	Durham.
Serpula	1	,,
3	3	

Class—CRUSTACEA.

Cythere	26	Durham, Northumberland, &c.
Kirkbia	1	Northumberland.
Prosoponiscus	1	
Estheria	1	
4	29	

Sub-Kingdom—MOLLUSCOIDA.

Class—Polyzoa.

Genera.		No. of Species.	Localities.
Fenestella		1	Durham, Northumberland.
Synocladia		1	„ „
Phyllopora		1	Durham.
Thamniscus		1	Durham, Northumberland.
Acanthocladia		1	„ „
Hippothoa		1	„ „
6		6	

MOLLUSCOIDA.

Class—Brachiopoda.

Athyris	1	Durham.
Lingula	2	„
Discina	1	„
Productus	2	„
Strophalosia	4	Durham, Northumberland, Yorkshire.
Streptorhynchus	1	Durham, Northumberland.
Camerophoria	3	„ „
Trigonotreta	6	„ „
Martinia	2	„ „
Cleiothyris	1	„ „
Epithyris	2	Durham, Yorkshire, Northumberland.
Crania	1	
Spirifera	6	
Spiriferina	2	
Terebratula	2	
15	36	

Class—Pelecypoda.

Pecten	1	Durham, Northumberland.
Lima	1	Durham.
Monotis	3	Durham, Northumberland, Yorkshire.
Aucella	1	„ „
Avicula	3	„ „
Gervillia	4	Durham.
Arca	2	„
Mytilus	2	Yorkshire, Durham, Northumberland.
Edmondia	1	Durham.
Nucula	1	„
Leda	1	Durham, Northumberland.
Solemya	4	Durham.
Cardiomorpha	1	Durham, Northumberland.
Pleurophorus	1	Durham, Northumberland, Manchester.
Myalina	1	Durham.
Myoconcha	1	„
Tellina	1	„

	Genera.	No. of Species.	Localities.
Schizodus		5	Yorkshire, Manchester, Durham, Northumberland.
Astarte		2	Durham, Northumberland.
Allorisma		1	" "
	20	37	

Class—GASTEROPODA.

Calyptræa		1	Durham.
Chemnitzia		1	"
Chiton		3	"
Chitonellus		4	"
Dentalium		1	"
Natica		2	"
Pleurotomaria		3	"
Rissoa		1	Durham, Manchester.
Straparollus		1	Durham.
Turbonilla		4	"
Turbo		5	Durham, Manchester.
	11	26	

Class—PTEROPODA.

Theca		1	Durham.

Class—CEPHALOPODA.

Nautilus		1	Durham.

SUB-KINGDOM—VERTEBRATA.

Class—PISCES.

Acrolepis		3	Durham, Northumberland.
Cœlacanthus		2	" "
Dorypterus		1	" "
Gyracanthus		1	" "
Gyropristis		1	Near Belfast.
Palæoniscus		11	Durham, Northumberland.
Platysomus		2	" "
Pygopterus		2	" "
	8	23	

Class—REPTILIA AND AMPHIBIA.

Dasyceps		1	
Lepidotosaurus		1	
Protorosaurus		2	

FOOTPRINTS.

Actibatis		1	Annandale, Scotland.
Batrichnis		1	" "
Chelaspodos		1	" "
Chelichnis		7	" "
Herpetichnus		2	" "
Saurichnis		1	" "
	9	17	

NUMERICAL SUMMARY OF THE PERMIAN FOSSILS OF ENGLAND, IRELAND, AND SCOTLAND.

	Species.
Plantæ	26
Protozoa	5
Rhizopoda	12
Actinozoa	5
Echinodermata	2
Annelida	3
Crustacea	29
Polyzoa	6
Brachiopoda	36
Pelecypoda	37
Gasteropoda	26
Pteropoda	1
Cephalopoda	1
Pisces	23
Reptilia	17
15	229

PLATE XVI.

PERMIAN FOSSILS.

1. *Voltzia heterophylla.* Permian.
2. *Walchia Schlotheimii.* Do.
3. *Synocladia virgulacea* (Phill.) Permian. Humbleton, Tunstall, &c.
4. *Fenestella retiformis.* (Schloth.) Permian. Tynemouth, Humbleton, &c.

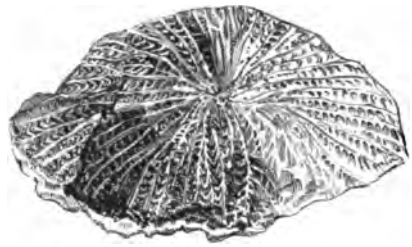
4a. Enlarged portion of Do. Permian. Humbleton, &c.

5. *Productus horridus* (Sow.) Permian. Humbleton, Tunstall, Tynemouth, &c.
6. *Strophalosia Morrisiana* (King). Permian. Tynemouth, Humbleton, &c.

PLATE XVI.

PERMIAN FOSSILS.

2



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5

6

1

4

4a

PART V.

MESOZOIC OR SECONDARY.

CHAPTER XXIX.

LOWER MESOZOIC STRATA.

Triassic.

Geographical Range and Physical Features.[1]—We now enter the next division or the Mesozoic series.

In the British islands the Triassic rocks occupy an extensive area, comprising the low plains in the north-west and north-east of England, and the central part of England. The New Red or Triassic sandstones appear in the low part of Lancashire, by Poulton, Preston, Ormskirk, and Liverpool, and occupy a large breadth in the midland counties, from Chester and Shrewsbury on the western portion, to Manchester, Congleton, Newcastle-under-Lyne, Cheadle, Ashbourne, and Nottingham on the east.

From Nottingham a long and continuous range of these red rocks runs northwards, resting nearly or quite conformably on the Permian strata, which also, in their turn, unconformably overlie the Coal-measures, Millstone Grit, and Carboniferous limestone. This series occupies the vale of the Trent, and the vales of York and Mowbray, expiring in the broad estuary of the Tees.

Resuming our survey at Nottingham, it will be seen that the plain between that town, Leicester, Coventry, Warwick, Worcester, and Shrewsbury is chiefly filled with the Permian and New Red or Triassic sandstones and marls, except where the subjacent Coal-measures, Carboniferous limestone, and Cambrian rocks of Charnwood Forest stand up through them as islands in the Triassic plain, as they probably also did in the Triassic sea at the time of its deposition.

From Worcester southwards, the Severn Valley is chiefly occupied by the New Red series, which, after many sinuosities, and filling many depressions in the older rocks about Bristol, and the Carboni-

[1] Consult "The Triassic and Permian Rocks of the Midland Counties of England" (Mem. Geol. Survey, England and Wales), by E. Hull, F.R.S. 1869.

ferous limestone of the Mendip Hills, spreads out in the rich vale of Taunton and Exeter, and occupies an extensive range of sea cliff at the mouths of the Teign, Exe, Sid, and Axe.

Expanding from the main mass, patches of New Red appear in the interior of Devonshire, and in the cliffs of West Somerset at Watchet. The area now occupied by the Bristol Channel was doubtless a continuation of the Triassic plain, traces of which we have as far west as Bridgend on the north side of the Channel, skirting the South Wales coalfield, and, as before stated, at Watchet and Porlock on the south side.

In this long range and extended area, the New Red sandstone is everywhere marked by comparatively gentle undulations and simple physical features, relieved here and there by picturesque cliffs of sandstone over some pleasant river, such as the Mersey above Stockport, the Dee about Chester, the Don about Ashbourne, the Avon at Warwick, the Severn from Kidderminster to Gloucester and Aust Passage, through which they have cut their winding courses. Nowhere does the sandstone of this series rise into hills more than 1000 feet above the sea; the most conspicuous in feature are the Hawkstone ridges of Cheshire, and the hill on which stands Nottingham Castle and much of the town. The marly parts of the New Red are generally fertile, the sandy and pebbly parts less so, or even barren, as in some parts of Sherwood Forest, &c.

Type of the British Series.—The best general type is to be found in the vale of the Severn, where, between Tewkesbury and Newent, in a breadth of 10 miles and a total thickness of about 1350 feet, is exposed the sequence expressed in the following table:—

TABLE XLIII.—*Showing the General Succession of the Keuper and Bunter Beds for Britain.*

Keuper.	The several beds may be thus described in the order of their successive depositions:— *m.* Rhætic series, uppermost part of the Triassic group, comprising black shales and thin impure limestones with "Bone beds" passing into *l.* Pale greenish marls, differing only by the colour from the red series below. *k.* Red marls. *i.* Thin laminæ and white sandstone and greenish marls, with cubical sandstone casts, in cavities once occupied by rock-salt crystals. Now occurring as pseudomorphs. *h.* Red marls. *g.* Sandstone, white, yellowish, or brownish, generally full of oblique lamination, indicating shallow-water conditions and currents, with fish-teeth and bones, and stems of plants. Alternating with these are pale-blue shales much resembling those of the Lias, with small bivalve shells. This fossiliferous series makes traceable bands in the red series. *f.* Red marls, with gypsum in the upper part. *e.* Thin cellular quartz on beds of sandy marls. *d.* Thick red marls. This is the main part of the series (Calamites).

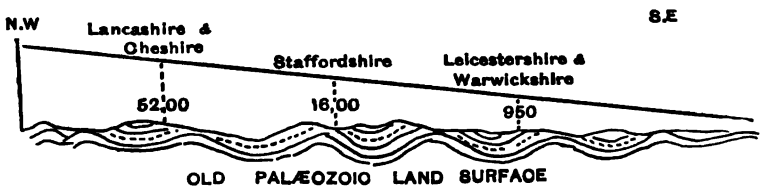
TABLE XLIII.—*Continued.*

Bunter.	*c.* Several beds of thin, white, and red sandstone, alternating with the argillaceous strata. *b.* White sandstones, sometimes firm, but often soft, and in a peculiarly concretionary or lumpy state—no fossils. *a.* Sandstones and conglomerates, 200 to 400 feet. Red sandstones, often conglomeratic with quartz pebbles, and interstratified with red sandy shales.

ariability in Physical Structure.—Like the underlying Permian rocks, the sandstones and marls of the Triassic series are almost barren of organic remains. Probably no group of rocks in the British islands exhibits such differences in the structure, thickness, and character of its several members, inequality of development being the marked feature both in England and Europe generally.

The variations in thickness in the direction of the general dip from the N.W. to the S.E., or the thinning away of these rocks towards the S.E., has been ably worked out by Professor Hull.

In Lancashire and West Cheshire the maximum thickness of the Bunter may be 1700 feet, and the Keuper 3450 feet, or together 5200 feet. In Staffordshire the maximum of the Bunter beds is estimated at 1600 feet, and the Keuper 1000 feet, or united 1600 feet. In Leicestershire and Warwickshire, on the line of deposition to the S.E., the maximum attained by the Bunter is only 100 feet, these being the pebble beds; the Keuper sandstones and marls are about 850 feet, or their united thickness is 950 feet. They have thus thinned away or lost on the line of deposition between Lancashire and Warwickshire no less than 4250 feet.



Palæozoic Land Surface.[1]—The Triassic rocks thicken out in Devon and Somerset to between 2500 or 3000 feet, being finely developed along the south coast of Devon, between Tor Bay and Sidmouth.

Recent borings in the south-eastern counties have determined that the Triassic rocks are wanting or absent there altogether; nowhere east of Burford, in Oxfordshire, and Northampton, have they been seen in any boring, or trial either for coal or water. At Burford they were

[1] Usher, Quart. Jour. Geol. Soc., vol. xxxii. p. 392, "On the Triassic Rocks of Somerset and Devon;" also "Subdivision of the Triassic Rocks between the Coast of W. Somerset and S. Coast of Devon," Geol. Mag., second ser., vol. ii.

touched at 742 feet from the surface, and measured 258 feet in thickness, resting at once upon the coal-measures. The total depth of the boring was 1200 feet, and this is the most easterly evidence we have of the presence of the true coal-measures. The boring for water near Northampton at the depth of 1000 feet has proved the presence of the Red Marls, resting upon the Carboniferous Limestone, without the intervention of the coal-measures. The trials east of Burford, in the neighbourhood of London, show that all traces of the Triassic rocks are lost. The borings at Kentish-town, Tottenham Court Road, Turnford, and Ware, north of London, give no trace of these Red rocks, the Cretaceous series resting at once upon the Upper Devonian slates; and at Ware, in Hertfordshire, the carr-stones or Neocomian beds (very thin here) rest upon Wenlock Limestone without the intervention of any strata between the thinly developed Neocomian and the Wenlock. All the Jurassic, Triassic, Carboniferous, and Devonian strata appear never to have been deposited in the latitude of Ware, or, with the exception of the Devonian at Turnford and Tottenham Court Road, between that area and London. Thus the evidence as to the complete thinning away of the Triassic rocks towards the east is complete.

Comparative Thickness from North to South-East.—Professor Hull in his memoir [1] gives the following table of the comparative thickness and range of the Triassic series along a south-easterly direction, from the estuary of the Mersey to Warwickshire and Leicestershire, and on to the Thames:—

Formations.		Lancashire and W. Cheshire.	Staffordshire.	Leicestershire and Warwickshire.
		Feet.	Feet.	Feet.
Keuper Series.	Red marl,	3000	800	700
	Lower Keuper sandstone,	450	200	150
Bunter Series.	Upper mottled sandstone,	500	50 to 200	absent.
	Pebble beds,	500 to 750	100 to 300	0 to 100
	Lower mottled sandstone,	200 to 500	6 to 100	absent.

These estimations as to thickness are founded upon measurements of vertical sections by the Geological Survey, along a given line of country between the estuaries of the Mersey and the Thames.

Original Deposition.—A plain of distribution so definite and uniform in its results cannot be attributed to local causes, but is connected with the original distribution of the sediment of which the beds are formed and the source from which it was derived. That source was the *great continent which occupied the North Atlantic* during this and other early geological periods, and the thinning away of the strata is evidently due to the increase in distance towards

[1] Mem. Geol. Surv. England and Wales: "The Triassic and Permian Rocks of the Midland Counties of England," p. 108; *ib* Q. J. Geol. Soc., vol xvi., "On the S.-E. Attenuation of the Lower Secondary Rocks of England."

the south-east of England from the source of supply. Prof. Hull supposed, and rightly, that they terminated along the sides of the barrier of older Palæozoic rocks, which underlie the Jurassic and Cretaceous formations of the Eastern counties.[1]

The Trias in its wide range through England rests with more or less unconformability on all the older rocks—in many places on the Permian and Carboniferous, and also on the Cambrian rocks, as at Charnwood Forest, and the Silurian beds of Malvern, &c., and the Devonian of North and South Devon. It is also finely developed in the Vale of York, and ceases upon the Permian at Hartlepool and mouth of the Tees. The Keuper or uppermost division consisting of red marl can be traced, as we have seen, from the coast of Lancashire far to the west on both sides of the Bristol Channel, and occupies a larger area of surface in the midland counties than the rest of the Trias and Permian sandstone combined.

Positions and Subdivisions of the Triassic Rocks.—According to the researches of the Geological Survey as determined by Professor Hull, the following is the accepted British classification, with the foreign equivalents, and as such it forms a key to the maps of the Survey :—

TABLE XLIV.—*Showing the General Classification of the Triassic and Permian Strata.*

			Foreign Equivalents.	
Triassic Series.	A. 1. Rhætic or Penarth Beds, red, green, and grey marls, with white limestone at the top.			
	A. 2. New red marl	Red and grey shales and marls, sometimes micaceous, with beds of rock-salt and gypsum, containing *Estheria* and *Foraminifera* (Chellaston).	Keuper.	Marnes irisées.
	A. 3. Lower Keuper sandstone	Thinly laminated micaceous sandstones and marls (waterstones); passing downwards into white, brown, or reddish sandstone, with a base of calcareous conglomerate or breccia.	Letten kohle (?).	„ „
	B. Wanting in England		Muschelkalk.	Calcaire conquillien.
	C. 1. Upper mottled sandstone	Soft, bright-red, and variegated sandstone (without pebbles)	Bunter sandstein.	Grès bigarré, or Grès des Vosges (in part).
	C. 2. Pebble beds	Harder reddish-brown sandstones with quartzose pebbles, passing into conglomerate; with a base of calcareous breccia		
	C. 3. Lower mottled sandstone	Soft, bright-red and variegated sandstone (without pebbles)		

[1] This supposition has been verified, as stated above, through borings made for water supply in London, at Turnford and at Ware; in the latter case Silurian rocks are now known to underlie the Cretaceous in Hertfordshire.

TABLE XLIV.—*Continued.*

			Foreign Equivalents.	
PERMIAN SERIES.	1. Upper Permian	Red marls, with thin bedded fossiliferous limestones (Manchester).	Zechstein.	
	2. Lower „	Red and variegated sandstone (Collyhurst, Manchester) represented by .	Roth-todt-liegende.	Grès des Vosges (in part).
		Reddish-brown and purple sandstones and marls, with calcareous conglomerates and trappoid breccia. (Central Counties) . .		

Divisions of the New Red Sandstone.—Formerly the great mass of red rocks which in England overlie the Carboniferous system were classed together as New Red Sandstone. We now recognise them under two groups or systems. The lower of these we have considered under the Permian division, and as the upper member and close of the Palæozoic period. The facies of the whole fauna, although slightly changed, is decidedly Palæozoic. The upper division of the Red rocks, or the Triassic series, is physically much the same as the lower or Permian, yet the organic remains remind us of the advent of the great Mesozoic fauna and flora; this Triassic group, therefore, occupies the base of the Mesozoic or Secondary series. The threefold subdivision, although very distinct in Germany, disappears in other regions. Three subdivisions are there recognised—

1. The *Keuper* Marls, &c.;
2. The *Muschelkalk;* and
3. The *Bunter* Sandstone.

These rocks for the most part consist of bright-red sandstone, clays, and marls, with nodules, layers and veinings or strings of gypsum, beds of rock, salt, and massive beds of dolomitic limestone.

In England, supposing all the limestones and the red sediments mineralogically related to them to be present in one section, we should have, reposing unconformably on the Palæozoic rocks, the following series or classification, beginning from above:—

MESOZOIC.	Bunter and Keuper.	4. Series of coloured Marls.	Purple-coloured marls below the Lias. Alternations of red and bluish white marls, with layers and nodules of gypsum. Thin layers of argillo-calcareous stone. Red and bluish marls with gypsum and beds of rock-salt.
		3. Variegated red and white Sandstone. (Poikilitic of Conybeare.)	Red and white sandstone, mostly fine-grained, and often impregnated with salt. Red conglomerate, full of pebbles of older rocks.

Palæozoic.	Permian.	2. Magnesian Limestone.	Red and white marls.
			Thin-bedded compact limestone, with very little magnesia and few organic remains.
			Red and white marls and gypsum.
			White, yellow, or reddish magnesian limestone in thick beds, crystallised, compact, or earthy, and containing marine organic remains.
			Marl slate, in thin layers, occasionally enclosing fishes.
		1. Yellow or purple sand and sandstone and marl.	An extremely variable series of sandstones, sands, and clays, of various colours, irregular thickness, and much local diversity of character. Plants like those of the coal-measures.

Rock-Salt.—Cheshire unites with the southern part of Lancashire and the northern part of Shropshire into a great plain, fifty miles long from north to south, and about twenty-five or thirty wide.[1] It is bounded on the east and west, and interruptedly on the south, by ranges of carboniferous hills; and the internal area is divided by two ranges of rising ground into three minor plains, which serve to conduct the Dee, the Weaver, and the Mersey to the Irish Channel. The range of Delamere Forest on the west, and an undulated tract ranging nearly westward to Halton and Runcorn, define the drainage of the Weaver, and include the most abundant sources of salt. Scarcely any rock-salt is found except in this limited tract. On approaching the estuary of the Mersey, the ridges which bound the plain approach one another at two points, and suggest the idea of the included plain having been once a lake.

Accumulation of Salt.—The mode of accumulation, judging from the associated materials, leads us to believe that it took place in "extensive basins of deposit, subject to incursions from the sea, in which the water underwent concentration," until its gypsum and salt were thrown down, chemically precipitated, or supersaturated. The prevalent type of sedimentation was that of open sea.

The salt which lies under the Cheshire plain is found to thicken, at least partially, toward the contraction of the valley; it does not, however, lie beneath the whole surface of the low ground, nor indeed in one connected mass, but occurs in detached flattened masses of limited area. The rock salt of Northwich ranges north-east and south-west, and its breadth is about three-quarters of a mile. The upper bed is thickest on the north-west, and thins off towards the south-east.

Two beds of salt at Northwich, &c.	Three beds at Lawton.
Rock salt, 84 to 90 feet.	Marl, &c., 42 yards.
Parting of marls, &c. } 30 feet.	Salt, 4 feet.
	Marl, &c., 10 yards.
	Salt, 12 feet.
Rock-salt, 96 to 117 feet, and more.	Marl, &c., 15 yards.
	Salt, 24 yards.

[1] Holland, Trans. Geol. Soc., vol. i. first series.

The upper bed has been worked through only at Northwich and Lawton. No marine remains occur with the salt, or in any way associated with it. The purest part in the upper bed is about three or four yards above the bottom, and about four feet in thickness; the purest part of the lower bed occurs twenty or twenty-five yards deep, and is five or six yards thick, below which the salt becomes earthy, as above. This is the part worked. The salt is not stratified, but divided into vertical prisms of various polyhedral forms, and different dimensions, sometimes a yard or more in diameter. The sides of these prisms consist of pure white salt. Gypsum abounds in the marls associated with the salt, the most abundant variety being the fibrous kind, which traverses the marls in net-like ramifications.

Probably what is now the salt-field was once a salt-water lake, separated from the sea by some natural barrier; the evaporation of the water caused supersaturation and precipitation of the salt, which subsequently became covered with the laminated marls. The lake or lagoon may have been fed by saline water through river action or the draining of Palæozoic rocks, the conditions resembling those of the Jordan and Dead Sea at the present time—supersaturation only causing the accumulation, there being no outlet to the waters of this inland sea.

Rock-salt is a frequent but not an exclusive production of the red marl and red sandstone, the mines of Wielitzka being in Tertiary sand, those in the Salzburg Alps in limestone of the Jurassic period.

By far the larger proportion of ordinary springs, from whatever strata they issue, yield chloride of sodium, sometimes in very large quantity, and it is important to know that bromine and iodine, which are stated to be always existent in the actual sea-water, very generally accompany the muriatic salts in common springs. The *rock-salt* of Cheshire is believed to be entirely devoid of bromine and iodine, though the *brine springs* of the same district are found to contain both.

Absence of the Muschelkalk in Britain.—One distinctive feature in the Trias of England, as distinguished from that of Germany and France, is the absence of the Muschelkalk or central calcareous member. This absence must not of itself be taken as evidence of unconformability; it was a break in the succession through local changes in the physical geography of the Triassic area during the deposition of the Bunter and Keuper strata, or through such depression over the area in Europe where the Muschelkalk is developed as would allow of the interpolation of a special marine fauna whose general facies was not lost all through the Keuper period, as proved by the deposition of the St. Cassian, Hallstadt, and Kössen beds, finally culminating in the deposition of the Rhætic series, a transitional group from the Trias into the Lias. The variable nature of the Triassic strata, and the conditions under which they were deposited, must not be overlooked when the European series are correlated with those of Britain.

Dolomitic Conglomerate.

Local Distribution.—Probably the Dolomitic Conglomerate of the Bristol area may occupy the same stratigraphical position as the Muschelkalk; it occurs only and entirely within the Bristol coal-basin, or upon those older rocks comprising it.[1] In the southern portion of the coalfield, or between Bristol and the northern flanks of the Mendip Hills, it is the so-called "overlie" of the colliers. Few pits are sunk in which the Dolomitic Conglomerate is not seen to unconformably cover and overlie the coal-measures. It marked a shore line in Triassic times, and now occupies the same position; and it must also have been extensively spread out, or over a shallow sea-bed or lake; it averages about 20 feet in thickness, but frequently rises here and there into bold and picturesque cliffs 40 to 50 feet high. This conglomerate (in places a breccia) is a marked feature in the physical structure of the Bristol coal-field, to be understood only in connection with the limited and complicated area occupied by the Palæozoic rocks of the Bristol and southern part of the South Wales coalfield.[2] This conglomerate has yielded two genera of Dinosauria,[3] *Thecodontosaurus* and *Palæosaurus*. The *contained* or derived rocks are chiefly Carboniferous limestone, Millstone Grit, and Coal-measure sandstones, cemented together by carbonate of lime, iron oxide, and magnesia, whence the name "Dolomitic or Magnesian Conglomerate." Beds of yellow, fine-grained, thick-bedded impure Magnesian limestone are conspicuous on the coast near Clevedon in Somersetshire, and also on the Glamorganshire coast—they lie above the conglomerate, and pass into the Red sands and marls above.

Fauna of the Triassic Rocks.

The organic remains of the Bunter and Keuper are comparatively few. The conditions for life or preservation could hardly have been congenial. The land possessed a flora which, from the fragments known, must have consisted of large, cypress-like, coniferous trees, *Voltzia*, *Walchia*, *Calamites*, &c. A small bivalve crustacean, *Estheria* (*E. minuta*), abounds in places in the white and red marls, associated with *Pullastra arenicola*, a bivalve shell which is common through the uppermost portion of the Keuper marls and Rhætic beds, but does not range into the Lower Lias.

The Keuper marls and sandstones in Worcestershire and Warwickshire contain, near their upper part, and in marly concretions or thin lenticular beds, many fish-remains, mostly represented by teeth and dorsal spines or defences belonging to the genera *Hybodus* (*H. Keuperi*, *H. minor*), *Acrodus* (*A. minimus*), *Lophodus*

[1] The conglomerate occurs on the south side of the Mendip Hills, resting upon the Carboniferous and Old Red sandstone series. South of this range there is little doubt that an extensive coalfield occurs, although hidden by the newer rocks.

[2] *Vide* Etheridge, Q. Journ. Geol. Soc., vol. xxvi. p. 174, and Geological Observer, De la Beche, pp. 476–496.

[3] See Riley and Stuckbury, Geol. Trans., vol. v., 2nd ser., p. 349.

(*L. Keuperianus*), *Saurichthys* (*S. acunimatus*), and scales of *Lepidotus*. In the Keuper sandstones of many parts of England occur the footprints, occasional bones, jaws, &c., of *Labyrinthodon*, *Cheirotherium*, *Hyperodapedon*, *Cladyodon*, and *Rhynchosaurus*, and in the Elgin sandstones of Scotland, *Stagnolepos* (*S. Robertsoni*) and *Telerpeton* (*T. Elginense*). The earliest known European mammal (*Microlestes*), probably marsupial, has been found in the highest member of the Keuper marls near Watchett. *Microlestes* had been previously discovered in this county by Mr. C. Moore in the Rhætic series in fissures in the Carboniferous limestone near Frome. No less than thirty teeth of this insectivorous marsupial mammal from one locality[1] have rewarded the researches of Mr. Moore. The genera *Thecodontosaurus* and *Palæosaurus* occur only at the base of the Keuper, in the Dolomitic conglomerate; *Hyperodapedon* has occurred with *Telerpeton* in the Elgin beds in Scotland, the Keuper sandstones of South Devon, and in the same series of beds in Warwickshire.[2] The distributional area or extension of this remarkable reptile is confirmed from finding *Hyperodapedon* in Maldei in Central India, and from rocks of the same age. *Dicynodonts* occur in the same Indian strata, thus throwing much light upon the *reptiliferous formation* of Southern Africa, the Triassic or Permian age of which is highly probable. Besides *Telerpeton* and *Hyperodapedon*, the genus *Rhynchosaurus* occurs in the Trias of Cheshire at Grinshill, associated with the footprints of *Cheirotherium*.

The genus Labyrinthodon, of which we have five if not six species, chiefly illustrates the Keuper sandstones of Warwick and Leamington, &c. The species known are *Labyrinthodon leptognathus* (1, 2, 3); *L. Salamandroides* (2); *L. ventricosus* (1, 3); *L. conicus* (1); *L. scutulatus* (1, 2); *Mastodonsaurus* (*Labyrinthodon*) *Pachygnathus* (1, 2); *M. giganteus* (1); *Diadetognathus varvicensis* (5); *Cladyodon Lloydii* (1); and *Hyperodapedon* (5).[3]

Labyrinthodon (*Daseyceps*) *Bucklandi* occurs in the Permian of Kenilworth and Coventry. It was formerly assigned to the Keuper.[3]

The lower Keuper sandstone at Bromsgrove has yielded the singular and unique fish *Dipteronotus* (*D. cyphus*), differing entirely from any known genus.[4] We know not to what family to assign this species. The presence of the Homocercal tail raises a question of stratigraphical significance—in this with other characters differing from any form occurring below the Lias; only one specimen is known.[5]

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[1] Plieninger in 1847 discovered the molar tooth of this Triassic mammifer in the bone-bed of Würtemberg; he inferred its nature and affinities from the double fangs to the teeth, and from the form and number of the cusps on the flat crown; the nearest ally of *Microlestes* amongst existing mammals appears to be the marsupial and insectivorous *Myrmecobius* of Australia; but whether this early mammal was marsupial or placental, it is really difficult to say positively. The first traces of mammalian life in North America occur also in the Trias, *Dromatherium* appearing about the same time in that area. The genus *Hypsiprimnopsis* of Mr. Boyd Dawkins, found in the upper marls of the Keuper, is probably really *Microlestes*. The lower jaw only of *Dromatherium* has been as yet obtained. Each ramus contains ten small molar teeth in continuous series, one canine and three conical incisors.

[2] See Huxley and Whitaker, Q. Jour. Geol. Soc., vol. xxv. pp. 138–158. This jaw of *Hyperodapedon* is the *first and only fossil yet found* in the New Red sandstone of Devonshire. Professor Huxley concludes that *Hyperodapedon* is nearly allied to the living *Sphenodon* (*Hatteria*) of New Zealand—both possess *amphicœlous vertebræ*, both have beak-like præmaxillæ, not anchylosed together, both have similarly formed jaws; in each also a single row of teeth in the mandible bites between two rows of teeth fixed to a plate formed by the union of the maxilla with the palatine bone. Localities, 1. Warwick; 2. Leamington; 3. Cubbington; 4. Leek Woolon; 5. Cotton End.

[3] Consult the able paper by Professor L. Miall on Labyrinthodontia, Q. Jour. Geol. Soc., vol. xxx. pp. 417–434.

[4] Egerton, Q. Jour. Geol. Soc., vol. x. p. 369.

[5] Now in the Geol. Survey Coll. in Jermyn Street.

Foreign Localities.

The distribution of the Poikilitic or Triassic series in Europe is extensive, especially in France and Germany, where, mantling round, or resting against the mountain tracts of the Vosges, Schwarzwald, Odenwald, Spessart, Thüringerwald, and Harz, the sandstones and marls contain the Muschelkalk (beds wanting in England), rich in fossil remains, and closely resembling the Lower Lias of England.

In several districts, especially in Würtemberg, the sandstones and marls also contain organic remains, of both animals and plants, which are entirely distinct from those known to belong to the older formations, but greatly resemble those of the Lias and Oolites, so that the foreign localities supply us with links in the chain of geological history which were wanting in England, and which were necessary to a true estimate of the relation of the Saliferous system to earlier and later deposits.

North-East of Germany.—The north-east of Germany gives us the following section of the saliferous system :—

3. Variegated marls (*Keuper, marnes irisées*) with gypsum and the usual characters of the strata.

2. The Muschelkalk admits of subdivision into two, or perhaps three parts, which may be distinguished by their respective types of organic remains.

1. Variegated sandstone. (*Bunter sandstein, grès bigarré.*)

Below are Zechstein and Roth-liegende.

The following table will show the relations of the three tracts :—

England.	France.	Germany.
Variegated marls. (Keuper.)	Marnes irisées. Muschelkalk.	Keuper. Muschelkalk.
Variegated sandstone. (Bunter.)	Grès bigarré. Grès des Vosges.	Bunter Sandstein.

With respect to organic remains, it may be sufficient to remark that they are found locally in abundance in all the members of the Triassic series in Germany and France, while hitherto they have remained almost undiscovered in England.

Saliferous Beds.—It appears that the greater part of the salt beds of Germany occur in the Muschelkalk, between Magdeburg and Osnabrück, and in the Valley of the Neckar in Würtemberg. At Vic, Baden, and Lons le Saulnier, the salt lies in red marl, along the north side of the Tyrolean Alps, in Red sandstone (Altenau, Berchtolgaden), and it is possible that the abundant salt-works on both sides of the Carpathians in Transylvania and Moldavia may occur in this series. The salt of European Russia is connected with the New Red and Permian sandstone.

2. Variegated Red sandstone. (*Bunter sandstein* of Germany, *grès bigarré* of France.)—This is extremely similar to the New Red sandstone of England, and also contains, locally, abundance of organic remains, both of animals and plants.

1. The strata above named rest, in some places unconformably,

upon a vast thickness of Red sandstone, in general much coarser, and more like a conglomerate than the variegated Red sandstone, the pebbles of quartz, contained in abundance, appearing to be derived from the ruins of portions of the Primary rocks of the range of the Vosges. The magnificent precipices down which the road descends to Saverne, among grand old woods and torrents, are formed by this rock; and the resemblance which it bears to the Old Red Sandstone conglomerate of Monmouthshire is remarkable. In other cases, and especially in hand specimens, this rock appears to resemble the coarse Red sandstone of Dumfriesshire and of Penrith Beacon; and as these rocks overlie the Carboniferous series, this comparison may, perhaps, be exact.

Muschelkalk.—A compact and argillaceous Limestone, of a light grey or smoky colour, with partings of marl, containing *Encrinites moniliformis*, *Ceratites nodosus*, *Limæ*, and other shells analogous to those of the Liassic system, and remains of reptiles (*Nothosaurus*, *Placodus*, &c.) Near Luxemburg it is very thin, and may easily be mistaken for Lias; near Saverne it is much thicker, and more characteristic. At Bourbonne les Bains it is a true magnesian limestone. The Muschelkalk underlies the Keuper, and includes beds of dolomite, gypsum, and rock-salt. This limestone, which is wholly unrepresented in Britain, abounds in fossil shells, many of peculiar type. Among the Cephalopoda the genus *Ceratites* is significant and decisive, *C. nodosus* being essentially a species confined to this deposit; so with the crinoidal genus, *Encrinurus* (*E. liliiformis*) and *Ophiura prisca*, *Aspidura* (*A. loricata*); associated with these occur the remains of the sauropterygian genus *Placodus* (*P. gigas*), also confined to the Muschelkalk. This singular reptile probably fed upon the shell-bearing mollusca, its short flat teeth being used for the purpose of shell-crushing. The Muschelkalk is the great storehouse of Triassic marine life. Those bivalve shells most common are—

Cardium pectinatum, *Myophoria lineata*, *Schizodus*, *Mya musculoides*, *M. elongata*, *Lima lineata*, *L. ovata*, *Avicula socialis*, *Pecten reticulatus*, *Terebratula communis*, and *T. subrotunda*. Among the Gasteropoda occur *Calyptræa*, *Trochus*, and *Turritella*.

Among the Reptilia, *Phytosaurus*, *Nothosaurus*, and *Rhynchosaurus*.

The flora of the Triassic period largely consisted of ferns (some arborescent), equisetaceæ, coniferæ, and cycadeæ. Nine genera only illustrate the British Trias. These are *Calamites*, *Equisetites*, *Echinostachys*, *Naidites*, *Sagenaria*, *Cyatheites*, *Dictyopteris*, *Walchia*, and *Dictyophyllum*. Many of the Continental forms are totally absent from Britain. The most distinctive feature in the flora of the earlier Mesozoic period was the commencement and abundance of the Cycadeæ, which continued to be greatly developed until the middle of the Lower Jurassic period, or termination of the deposition of the Inferior Oolite. The most abundant and chief genera occurring above the Trias are *Pterophyllum*, *Zamites*, *Otozamites*, *Pterozamites*, *Podozamites*, &c. *Voltzia* or *Ullmannia* is not known above the Permian in England.

The fauna also of the red series, or the sandy and marly strata throughout Europe, is comparatively poor. Corals and Foraminifera abound in the Alpine beds; the Echinodermata, through the crinoids, are greatly developed individually, many of the rocks being entirely composed of the dismembered portions of *Encrinus liliiformis*, *Cidaris*, and other *Echini*.

CHAPTER XXX.

RHÆTIC, AVICULA CONTORTA, OR PENARTH BEDS.

Rhætic or Avicula contorta *Beds*, Portlock, 1843.
Kössener Schichten, *von Hauer*, 1853.
Oberes St. Cassian, *Escher*, 1853.
Gervillien- (Kössener) Schichten, *Gümbel*, 1856.
Die Zone der Avicula contorta, *Oppel*, 1859.
Infra-Lias du Département de la Côte d'Or, *Jules Martin*, 1860.

Penarth Beds of the Geological Survey.

Stratigraphical Relations.—These and numerous other terms constitute the synonymy of the *Avicula contorta* zone, a name given by Colonel Portlock in 1843 to beds in the North of Ireland containing the shells *Avicula contorta* and *Pecten valoniensis*. This series was then classed with the Lower Lias; but research into the history and structure of the Rhætian Alps and their palæontological contents resulted in clearly determining that the fauna of the *Avicula contorta* or Rhætic beds belonged to the Triassic rather than to the Liassic group, especially as exemplified by its Fishes and Reptilia; and there cannot be any doubt that the fauna of the *Avicula contorta* zone has closer affinities with that of the Kössener Schichten of the Tyrol and the Upper St. Cassian beds of Germany (Escher) than with the Lias, from the fact that most of the species found in the Rhætic beds do not pass into the Lower Lias. The chief species of Mollusca are *Cardium rhæticum*, *Pecten valoniensis*, *Pleurophorus*, *Avicula contorta*, and *Schizodus* (*Myophoria*) *angulatus*. Fishes: *Nemacanthus*, *Acrolepis*, *Sargodon*, *Saurichthys*, *Gyrolepis*, *Ceradotus*, &c. The Reptilian genera *Ichthyosaurus* and *Plesiosaurus* first occur here, but are different species from those of the Lower Lias. The earliest known mammal (*Microlestes antiquus*) occurs in the Rhætic beds of this country as well as in those at Dierloch, in Würtemberg.

Stratigraphical Position.—The stratigraphical place of the Penarth, Rhætic, or Avicula-contorta beds is between the top of the Red Marls and the bottom of the *Ostrea liassica* limestones (base of the Lias), and they include the Black Shales, with their interstratified sandstones, impure limestones, and bone-beds, &c. Usually the base

consists of a set of grey, green, cream-coloured, and pale-red marls (Tea-Green Marls), which insensibly pass up to the dark shales full of fossils. Prior to their recognition in Britain by Strickland in 1842,[1] and Portlock's notice of them under the name of "shale," with *Avicula contorta* and "loose gritty marl," containing *Pecten valoniensis*,[2] little or nothing was known of the singular fauna of the series, nor their relation to widely-spread and contemporaneous beds in Europe.[3]

Origin of Name.—The term "Avicula contorta zone" was adopted from the presence of a species of Avicula (*Avicula contorta, Portlock*) originally and abundantly found in these beds near Port Rush in the North of Ireland, but now also commonly found in every Rhætic section in the kingdom. These shales, sandstones, and impure limestones in Britain appear to be the equivalents in time and almost in condition of the upper St. Cassian beds in Switzerland and Germany, and the Kössener Schichten series of von Hauer in Austria. Colonel Portlock, in his report upon the Geology of Londonderry in 1843, termed them "shales with *Avicula contorta* and loose gritty marl containing *Pecten valoniensis*." The abundance and persistence of the former shell gave rise to the name "*Avicula contorta* zone," as contra-distinguished from certain zones of the Lias above containing Ammonites, these "contorta," shales, &c., being always below the zone of *Ammonites planorbis* of the Lower Lias, the first or lowest ammonite known in the British strata.

The name "Penarth beds" is based upon the highly developed and typical condition of the series at Penarth Head and Lavernock Point, near Cardiff.[4] This name is now received and adopted for this group by the Geological Survey, and has become generally used. We question if the term "Rhætic" was not equally good, as expressive of the great development of these beds in the Rhætian Alps, bordering the Plain of Lombardy, where the formation is from 3000 to 4000 feet thick, but in Britain varying from 50 to 100 feet.

Range of the Rhætic Beds.—From Redcar in Yorkshire to Lyme Regis in Dorsetshire, the *Avicula contorta* beds have occurred wherever the junction of the Trias and Lias is revealed; and they retain throughout their physical and palæontological characters, consisting of black pyritous shales and thin impure limestones crowded with ill-preserved (but constant) species of Mollusca and Fish-remains.

The most complete sections in England are to be studied at Aust

[1] Proc. Geol. Soc., vol. iii. p. 586.

[2] Report on the Geology of Londonderry, 1843, pp. 126-127.

[3] Forty-five years have now elapsed since von Buch in 1828, and Alberti in 1834, first noticed and described those now well-known strata that strike through England under the Lias. Quenstedt (1846), Emmerich (1849), von Hauer (1853), Escher (1853), Gümbel (1856), Oppel (1856-59), Dr. Wright (1860), C. Moore (1861), have all since written upon them.

[4] It was thought desirable to have a British equivalent term for these beds, and their development in Penarth Roads (Penarth to Lavernock) suggested the appropriate name. Nowhere else in Great Britain can they be studied so advantageously or thoroughly.

Passage and Garden Cliff, Westbury (Gloucestershire), Penarth Cliff (Glamorganshire), and St. Audrey's Slip (Somersetshire); nowhere do they exceed 50 feet in thickness, but lithologically and palæontologically they are the same throughout.

Continental Range.—On the Continent of Europe this Rhætic or *Avicula contorta* zone has also a most extensive geographical range. Its deposits are met with in Germany, Switzerland, France, Hungary, and as far north as Sweden. We find them in Würtemberg, near Tübingen, Stuttgart, and Göttingen; in Baden, at Bamberg and Baireuth; near Brunswick, Hildesheim, and Hanover; also in the Vaudois Alps, the Canton of Aargau, and near Basel and other localities in Switzerland.

The Côte d'Or, Aveyron, Herault, Luxembourg, and Belgium possess this transition group in greater or less development; it varies in thickness from 40 to 3000 feet throughout its distribution in Europe.

Faunal Value.—Our knowledge of the fauna is incomplete, owing to the physical structure of the fissile and shaly nature of the beds, no limestone of appreciable and constant thickness occurring in the series.

Typical Localities.—In the famous sections at Aust Passage, Westbury or Garden Cliff, Wainlode, &c., fifty species have been collected. In the cliffs near Penarth, probably the most complete section in Britain, nearly every known British species has been obtained.[1] This section is especially rich in the Mollusca, of which 15 species occur, and 10 species of fish; at Barrow-on-Soar the complete series was cut through; and the railway cutting at Elton, near Nottingham, exhibited the series in conjunction with the gypsiferous marls below. They have been continuously traced as far north as Gainsborough, wherever the two series have been seen in position, and they are known in the West Riding of Yorkshire, and on to near Redcar.

Succession of Triassic Rocks.—We have not in the British islands, in one section (or all united), a complete or even representative series of strata that can be co-ordinated with the deposits commencing with the Muschelkalk, which in time, though not in condition, paralleled our Bunter and Keuper deposits. These thick strata, either of fresh-water or marine origin, and almost devoid of life, stand alone. Their final close through elevation within the British area gave us a series of deposits known as the Rhætic series of Middle and Eastern Europe. Continental changes alone can only account for our not possessing the Muschelkalk, the St. Cassian or Hallstadt beds, the Dachstein, Kössen or Upper St. Cassian beds of Switzerland, and other groups occurring in typical areas in Europe.

The nature of the fauna is suggestive of geographical rather than

[1] See the vertical sections of the typical Rhætic beds and localities constructed by Messrs. Bristow and Etheridge. (Sheets Nos. 46 and 47 of the Geological Survey.)

climatic changes, the species being developed either in shallow, estuarine, or brackish waters, and consequently dwarfed and stunted in growth; and although we possess many of the European forms, there is yet, in those regions on the Continent where the series are fully developed, a fauna the magnitude of which is nearly unequalled by any British deposit.[1]

Distribution.—The distribution of the Penarth (Rhætic) beds over much of Europe is a very marked feature both physically and palæontologically; it determines the close of the Triassic sandstones and marls almost everywhere, and commences in Britain new conditions of life through a fauna closely allied to, and perhaps migratory or descendant from, the Muschelkalk of Germany, as well as the Kössener Schichten and St. Cassian beds of Central Europe. We can co-ordinate through the fauna of the Austrian, Lombardian, Hanoverian, Bavarian, Swiss, and French series, the entire natural history grouping of the English and Irish Rhætic beds, thus clearly demonstrating the distribution of the then existing life over great and extended areas, and here apparently accumulated in shallow and almost inland or confined seas. This relationship with the Continental deposits is fully established through certain mollusca which ranged through the Rhætic seas, and which at Penarth, as in Lombardy, &c., abound in the black shales, bone-bed, and impure limestones exposed along the coast.

The Severn with its magnificent vale is classic ground, and along its banks and in the valley and estuary occur numerous expositions of the Penarth series—notably at Garden Cliff (Westbury), Aust, Little Stoke, and St. Audrey's near Watchet, on its eastern banks, and grandly from Penarth Head to Lavernock; also at Barry Island, with inland sections near Bridgend. Its most westerly limit in Britain occurs along the line which marks the junction of the Trias with the southern outcrop of the South Wales coalfield from Cardiff to Bridgend, and is intermittently traceable from Newnham and Selbury to Wood Cliff, opposite Aust Passage Cliff, and on to Dunraven.

This type section at Penarth Head shows the position of the Rhætic beds resting upon the red, grey, yellow, and green tinted marls of the Keuper. Here too, better than at any other place known, are seen in one section the relative positions of the *Ostrea liassica*, *Ammonites planorbis*, and *Am. Bucklandi* beds of the Lower Lias. This section may be regarded as the type of the British series, nowhere equalled, and nowhere so easily studied as in the remarkable cliffs facing Penarth Roads.

Physical Aspect.—We must regard the Triassic epoch over much of what was then Europe as a terrestrial one, most of the lakes and seas being surrounded by masses of land. It is generally believed

[1] Consult the important work by A. Stoppani on this group of rocks: "Palæontologie Lombarde, ou description des fossiles de Lombardie," 4 series and appendix, 4to, Milan, 1858, &c. Also "Essai sur les Conditions générales des Couches à Avicula contorta, &c.," en Lombardie, 4to, Milan.

that the Keuper marls and Red Sandstone of Britain were deposited in a great fresh-water or brackish-water lake, for the most part destitute of outlet to the sea. In the British area subsidence may have taken place at the time when the lake or lakes became nearly full of sediment; a partial influx of the sea occurred over perhaps shallow bottoms, and the marine life that accompanied it, with the deposits that ensued, together constitute the Rhætic beds of England. These marine forms migrated from the east, where the St. Cassian and Hallstadt beds were deposited. Under these conditions the thin beds of North-Western Europe might have been accumulated in great part in shallow seas, or estuaries, in lagoons, or in occasional salt lakes of small or great dimensions.

We must, however, remember the conformity with the overlying Lias throughout England from Lyme Regis to Redcar, along one continuous line of sea-bottom, and also over nearly all Europe, especially Eastern France, Germany, and Italy; this great area being then occupied by Rhætic waters, and now by Rhætic fossils, which testify to the widely spread and universal condition of its fauna. Two large seas (basins) can be determined (whether inland lakes originally or not, we have no proof) in which the red rocks of the Trias and Rhætic above were extensively deposited, the largest being perhaps the Anglo-Parisian area, stretching from Penarth, Gloucestershire, Worcestershire, and Lincolnshire, to Luxembourg, Metz, Nancy, Dijon, and Néveres; the second great area being the Stuttgartian, the shores of which range from Mézières by Luxembourg, Besançon, Basle, Schaffhausen, Stuttgart, and Nuremburg, round to Coburg, with a central development through perhaps subsequent physical changes, along the Vosges Mountains.

The accompanying table shows the succession at Penarth from the Keuper Sandstone to the zone of *Ammonites planorbis*, with a short description of the general character of the beds.

TABLE XLV.—*Sequence of Penarth Beds from the Keuper Sandstone to the Lias.*

Liassic	Lower Lias	Zone of *Ammonites planorbis.*	Grey and pale yellow and light-coloured Limestones in thin bands with finely laminated shales between, containing *Ammonites planorbis, Ammo. Johnstoni, Modiola minima, Cidaris Edwardsii, Lima duplicata.* About 8 feet thick.
		Zone of *Ostrea liassica.*	Hard grey argillaceous Limestones, many of the beds having a blue centre, mostly thin-bedded and uniform, containing many fossils, especially *Ostrea liassica, Plicatula spinosa, Modiola minima, Lima duplicata, Monotis decussata, Carpenteria,* &c. Ten feet in thickness.

(*Continued on next page.*)

TABLE XLV. — (*Continued.*)

TRIASSIC.	Penarth or Rhætic Beds.	Zone of *Avicula contorta*, and *Cardium Rhæticum*.	Dark Shales and thin bands of impure Limestone, often pyritous, and grey micaceous sandstones: thin beds of bone breccias (bone-bed) near the base; sometimes two or three in the black shale; many fossils in the Shales and Limestones, the most important being *Avicula contorta*, *Cardium Rhæticum*, *Pecten valoniensis*, *Pullastra arenicola*, *Axinus*, *Modiolopsis antiquus*, *Placunopsis alpina*, *Gervillia præcursor*, *Ceratodus altus*, *C. latissimus*, *Nemacanthus filifer*, *N. monilifer*, *Hybodus reticulatus*, *H. minor*, *Saurichthys apicalis*, *S. acuminatus*, *Sargodon Tomicus*, *Gyrolepis Alberti*, and *Acrodus minimus*. These beds are finely exposed at Penarth, Westbury, Aust Passage, Uphill cutting (Weston-super-Mare), St. Audrey's slip, Watchet, and elsewhere.
	Keuper Series	Tea-Green and Red Marls.	Red Marls and bands of grey and greenish marly Clay, occasionally micaceous and numerous lenticular masses of Gypseous Marls, and veins of Gypsum and nests of *Estheria*. Foraminifera near the base.
		Keuper Sandstone.	Laminated Sandstone and interstratified Marls passing down into variously coloured Sandstones. Dolomitic Conglomerate at base overlying the older or Palæozoic rocks in Glamorganshire, Somersetshire, and Gloucestershire.

Fauna of the Rhætic Series.—The bone-beds at Westbury are pyritous and micaceous, abounding in fish-teeth, bones, coprolite, and other remains, and the thin sandstones are ripple-marked. At Aust Passage, Reptilian and Amphibian remains occur, both Ichthyosaurian and Plesiosaurian vertebræ and bones of Labyrinthodon, with defined spines of Hybodont and Cestraciont Fishes. These Fishes include Acrodus (*A. minimus*), Hybodus (*H. minor*, *H. reticulatus*, *H. raricostatus*), Nemacanthus (*N. filifer* and *N. monilifer*), with Saurichthys, three species (*S. acuminatus*, *S. apicalis*, and *S. longidens*). The Limestones above the Black Shales at the base of the Cotham marble at Aust have yielded several specimens of the ganoid fish, Legnonotus (*L. cothamensis*). Added to these are numerous teeth of many species of *Ceratodi* (order *Dipnoi*), chiefly *Ceratodus altus*, *C. gibbus*, *C. obtusus*, and *C. emarginatus*. With the exception of the genus Dipteronotus from the Lower Keuper of Bromsgrove, we have few or no Fish-remains until rising near to the Rhætic series at the close of the Keuper.

The *Avicula contorta* zone ranges from the Carpathians to the North

of Scotland, and from Sweden to the Plains of Lombardy. It is well developed in Northern Italy, where the group is of great thickness.[1] It occupies large areas in Austria, Rhætic Lombardy, Hanover, Savoy, Saxony, Bavaria, Bohemia, and France; and although in the British Islands it seldom exceeds 100 feet in thickness, yet the fact of its palæontological features agreeing in almost every essential character with the Continental deposits, enables us to co-ordinate through its fauna the entire series in this country with those of the Continent, as well as tends to establish and confirm those generalisations consequent upon the distribution of species over given areas through unlimited time.

Correlation.—In Sweden, Norway, Bohemia, and Hungary the Rhætic series occur only as a thin zone, but everywhere characterised by *Avicula contorta*, *Pecten valoniensis*, *Cardium Rhæticum*, *Pullastra arenicola*, *Anoplophora musculoides*, *Myophoria postera*, *Pleurophorus angulatus*, and species of *Schizodus* (*S. cloacinus*) and *Placunopsis alpinus*. In Saxony and Hanover it attains considerable thickness, associated with bone-beds and breccias like those of Westbury on Severn, Aust, Penarth, and Axminster. Every year establishes fresh evidence of its originally wide-spread condition over the central Triassic plain of England.

The coast at Londonderry and Antrim in Ireland gives unequivocal proof of its having once occupied an immense area, now covered by the waters of the North Atlantic, and buried beneath the ancient lava-flows and basaltic columns that form the coast-line of the Great Causeway; and, as before stated, an irregular but clearly-defined line, traceable from Redcar to the cliffs of Dorsetshire, attests its continuity through England, exhibiting on its way, through the varied but constant agency of denudation, the sections at Elton near Nottingham, Barrow, Leicester, Bristol, Bath, Beer Crocombe, Queen Camel, Westbury, Aust, Watchet, Axminster, and Penarth. The English Channel flows over that area whose western boundary-line stretches from Lyme Regis to Cherbourg, Valognes, and Caen. In Southern France the edge of the great Triassic basin is traceable from Montpellier on to Luxembourg; from Basle and the flanks of Jura to Stuttgart, Bamberg, Coburg, and Baireuth, its fossils, sandstones, and shales are determinable; along the Bavarian Alps, from Feldk near the Rhine to Salzburg, Gresten, and Vienna, they occur in great deposits constituting whole mountain ranges. In the northern parts of the plains of Lombardy, from Como, Azzarola, and Ternezzo to the Lake of Garda, they are also finely developed. This extensive distribution traces also the area of what must have been a great inland sea, in the midst of which the present Palæozoic lands of Britain stood up as islands, around and upon which the Upper Triassic rocks were deposited, their highest member being fossiliferous, and ushering in the great Jurassic epoch, whilst the Rhætic and Infra-Lias formed the base.

[1] See "Die Contorta Zone," Dr. A. von Dittmar, Munich, 1864; also Stoppani, "Geologie et Palæontologie des Couches à *Avicula contorta* en Lombardie," Milan, 1881.

The subjoined table exhibits the deposits in the Triassic Basin of Germany:—

TABLE XLVI.—*Triassic Deposits of Germany.*

RHÆTIC.	Rhætic (Infra-Lias). Grey sandy clays and fine-grained sandstones, containing *Equisetaceæ*, *Asplenites*, and *Cycadaceæ*. *Zamites*, *Pterophyllum*, *Cardium rhæticum*, *Avicula contorta*, *Estheria minuta*, the Reptilia *Nothosaurus*, *Trematosaurus*, and *Belodon*, and the Mammalia through *Microlestes antiquus*.
KEUPER.	Bunter Keupermergel, Gypskeuper. Bright red and mottled marls, with beds of gypsum and rock-salt. *Equisetum columnaris*, *Pterophyllum*, &c. Fish and Labyrinthodon remains. 300 to 1000 feet thick. Lettenkohle Kohlenkeuper. Grey sandstones and dark marls, and clays with abundant plants, sometimes forming thin seams of an earthy coal (Lettenkohle). The plants are *Araucarioxylon Thuringicum*, *Voltzia heterophylla*, with *Estheria*, *Ceratodus*, and remains of *Mastodonsaurus Jægeri*. About 230 feet.
MUSCHELKALK.	Upper Limestone (true Muschelkalk, in thick beds, with argillaceous partings). It abounds in organic remains. *Nautilus bidorsatus*, *Lima striata*, *Myophoria vulgaris*, *Trigonodus sandbergi*, and *Terebratula vulgaris* are characteristic, with *Encrinus liliiformis* in the lower, and *Ceratites* in the upper part of the rock. Marine, sometimes wholly made up of crinoidal stems. 200 to 400 feet. Middle Limestone and Anhydrite, consisting of dolomites with anhydrite gypsum and rock-salt. Few organic remains. 200 to 400 feet. Lower Limestone (Wellenkalk), consisting of limestones and dolomites. Poor in fossils, save in the limestone bands, some of which form a lower zone full of *Encrinus liliiformis*, while a higher zone contains *Myophoria obicularis*. 160 to 500 feet.
BUNTER.	Upper (Röth). Red and green marls, with gypsum in the lower part. 250 to 300 feet (*Myophoria costata*). Middle. Coarse-grained sandstones, sometimes incoherent. Voltzia sandstones, with way-boards of *Estheria* shales. Lower. Fine reddish argillaceous sandstone (Grès des Vosges), often micaceous and fissile, with occasional interstratifications of dolomite and of the marly oolite limestone called "Rogenstein." The Bunter division is generally barren of organic remains; the plants are *Equisetum arenaceum*, one or two ferns, and a few conifers (*Albertia* and *Voltzia*). *Myophoria costata* is found in the upper division all over Germany. Footprints occur on the sandstones, and bones of *Labyrinthodonts* and *Fish* have been obtained.

TABLE XLVII.—*Numerical Table of the Distribution of the Triassic and Rhætic Fossils.*

	Genera.	Species.	Bunter Beds.	Dolomitic Conglomerate.	Keuper Sandstone.	Keuper Marls.	Rhætic.	Pass Up.
Plantæ	9	12	$\frac{4}{7}$	...	$\frac{5}{5}$	...	$\frac{3}{3}$	...
Rhizopoda	16	35	...	...	...	$\frac{10}{35}$	...	...
Cœlenterata	5	8	...	...	...	...	$\frac{3}{8}$	...
Asteroidea	1	1	...	...	...	...	$\frac{1}{1}$	...
Annelida	...	...	...	...	...	...	...	...
Crustacea	5	5	...	...	...	...	$\frac{3}{5}$	...
Polyzoa	...	...	...	...	...	...	...	...
Brachiopoda	1	1	...	...	...	...	$\frac{1}{1}$	...
Pelecypoda { Monomyaria	9	17	...	...	...	...	$\frac{9}{17}$	...
Pelecypoda { Dimyaria	19	32	...	...	...	...	$\frac{12}{32}$	...
Gasteropoda	9	18	...	...	...	...	$\frac{9}{18}$	...
Pteropoda	none		...	...	...	...	...	...
Cephalopoda	none		...	...	...	...	...	...
Pisces	17	35	...	...	$\frac{2}{5}$	...	$\frac{16}{35}$	...
Reptilia	14	31	$\frac{4}{4}$	$\frac{3}{3}$	$\frac{11}{11}$	...	$\frac{3}{3}$	...
Mammalia	2	4	...	...	...	$\frac{1}{1}$	$\frac{3}{3}$	...
	107	199	$\frac{8}{8}$	$\frac{3}{3}$	$\frac{18}{18}$	$\frac{17}{18}$	$\frac{69}{195}$	...

The Poikilitic or Triassic group yields comparatively few fossils in the British Islands. In the Keuper occur a few plants, mollusca, and remains of fishes, augmented by the Warwickshire and Cheshire reptilia. The sandstones of Dumfriesshire, Liverpool, &c., have also yielded a large series of reptilian footprints. The bone-beds of Aust, Wainlode, Westbury, Penarth, &c. (Rhætic), lie at the top of the variegated marls, the tea-green marls of the Geological Survey, immediately below the Lower Lias, constituting a transition series between the Trias and the Lias, termed the Rhætic. The fossils are classed with the Trias in the following list:—

TABLE XLVIII.—*Organic Remains of the Triassic Rocks.*

PLANTÆ.

	No. of Species.	Bunter.	Keuper.	Rhætic.
Calamites	1	...	1	...
Cyatheites	2	...	1	1
Dictyophyllum	1	1	...	...
Dictyopteris	1	1	...	...
Echinostachys	2	2	...	...
Equisetites	1	...	1	...
Naidites	2	...	1	2
Sagenaria	1	...	1	...
Walchia	1	1	...	...
9	12	5	5	3

TABLE XLVIII.—*Continued.*

Genera.	No. of Species.	Bunter.	Keuper.	Rhætic.
CLASS—RHIZOPODA.				
Foraminifera.				
Bulimina	1	...	1	...
Cristellaria	2	...	2	...
Dentalina	3	...	3	...
Flabellina	4	...	4	...
Frondicularia	5	...	5	...
Glandulina	1	...	1	...
Lingulina	1	...	1	...
Lituola	1	...	1	...
Marginulina	1	...	1	...
Nodosaria	6	...	6	...
Nubecularia	1	...	1	...
Polymorphina	1	...	1	...
Planularia	3	...	3	...
Pulvinulina	1	...	1	...
Rotalia	1	...	1	...
Vaginulina	3	...	3	...
16	35		35	
Class—ACTINOZOA.				
Astrocœnia	4	...	...	4
Elyastræa	1	...	...	1
Montlivaltia	1	...	...	1
Rhabdophyllia	1	...	...	1
Thecosmilia	1	...	...	1
5	8			8
Class—ECHINODERMATA.				
Ophiolepis Dameri	1	...	...	1
Class—CRUSTACEA.				
Pollicipes	1	...	...	1
Candona	1	...	...	1
Cypris	1	...	...	1
Estheria	1	...	...	1
Tropifer	1	...	...	1
5	5			5
Class——BRACHIOPODA.				
Discina	1	...	...	1
MOLLUSCA.				
Pelecypoda (*Lamellibranchiata*).				
Avicula	3	...	...	3
Aviculopecten	1	...	...	1
Gervillia	3	...	...	3
Lima	1	...	...	1
Monotis	1	...	...	1
Ostrea	2	...	...	2
Pecten	4	...	...	4
Placunopsis	1	...	...	1
Plicatula	1	...	...	1
9	17			17
Anatina	4	...	...	4
Anoplophora	1	...	...	1
Arca	1	...	...	1
Astarte	1	...	...	1
Cardinia	1	...	...	1
Cardium	1	...	...	1
Cypricardia	2	...	...	2
Clidophorus	1	...	...	1
Leda	1	...	...	1
Conocardium	1	...	...	1
Modiolopsis	2	...	...	2
Modiola	1	...	...	1
Myacites	1	...	...	1
Myoconcha	1	...	...	1
Myophoria	3	...	...	3
Pleurophorus	2	...	...	2
Pleuromya	2	...	...	2
Pullastra	1	...	...	1
Schizodus	5	...	...	5
19	32			32
Class—GASTEROPODA.				
Actæonina	4	...	...	4
Cerithium	1	...	...	1
Chemnitzia	2	...	...	2
Chiton	1	...	...	1
Natica	2	...	..	2
Patella	2	...	...	2
Straparollus	1	...	...	1
Trochus	3	...	...	3
Turritella	2	...	...	2
9	18			18
CLASS—VERTEBRATA.				
PISCES.				
Acrodus	2	...	1	1
Acrolepis	1	...	...	1
Amblypterus	1	...	...	1
Ceratodus	9	...	1	9
Colobodus	1	...	...	1
Dipteronotus	1	...	1	1
Gyrolepis	2	...	...	2

May be L. Lias.

TABLE XLVIII.—*Continued.*

Genera.	No. of Species.	Bunter.	Keuper.	Rhætic.
Hybodus . .	6	...	1	6
Legnonotus .	1	...	...	1
Lepidotus . .	1	...	...	1
Nemacanthus .	2	...	...	2
Lophodus? .	1	...	1	...
Palæoniscus .	1	...	1	...
Pholidophorus .	1	...	...	1
Sargodon . .	1	...	...	1
Saurichthys . .	3	...	...	3
Squaloraia .	1	...	...	1
17	35		6	32
Class—REPTILIA.				
Cladyodon? .	1	1	...	...
Cheirotherium .	3	...	3	...
Diadetognathus	1	...	1	...
Ichthyosaurus .	2	...	...	2

Genera.	No. of Species.	Bunter.	Keuper.	Rhætic.
Labyrinthodon .	6	...	6	...
Mastodonsaurus	6	...	6	...
Plesiosaurus .	3	...	...	3
Palæosaurus .	2	...	2	...
Hyperodapedon	1	...	1	...
Rhynchosaurus .	1	1	...	...
Ryosteus . .	1	...	1	...
Stegonolepis .	1	1	...	...
Telerpeton .	1	1	...	...
Thecodontosaurus	2	...	2	...
14	31	4	22	5
MAMMALIA.				
Microlestes .	3	...	...	3
Hypsiprimnopsis	1	...	1	...
2	4		1	3

PART VI.

JURASSIC OR OOLITIC PERIOD.

CHAPTER XXXI.

GENERAL INTRODUCTION.

THIS great series of fossiliferous rocks first received the name of "*Oolitic*" from William Smith, owing to the nature and characteristic structure of many of its limestones in England.[1] The Continental geologists (those of France and Switzerland) applied the term "*Jurassic*" to the whole group, from the great development of the system among the Jura mountains, or the chain occupying the north-west frontier of Switzerland. Lithological names being objectionable, especially when applied to large groups of rocks, the term "Oolitic" for the group was abandoned, and the more characteristic name "Jurassic" is now universally received.

General Description.—Diversity of lithological structure is a marked feature throughout the whole of the Jurassic rocks wherever they have been recognised. The entire series, from the Lias to the Portland Oolite, varies over extended areas. The Jurassic rocks of France form a type by themselves, and differ essentially from the North German series, and also from the Alpine type. The general facies of the Jurassic system, traced into North-western India, also widely differs from that of Europe. That general uniformity of lithological character, which so distinguishes the Palæozoic and Triassic systems, no longer prevails through the Jurassic series; yet, with all these variations in aspect and petrological structure, the Fauna and Flora, as a whole, differ but little.

Distribution.—The Jurassic system covers a vast area in Europe, as well as nearly the eastern half of England, through which it ranges as a broad irregular band from the coast of north-east Yorkshire to Lyme Regis and Weymouth or Portland on the south; the western boundary is defined by the sinuous line of the Lower Lias and the plain of the New Red Sandstone, ranging from the Tees to the Exe. The continuity is not lost throughout its whole length. The New Red and Lias dip gently to the east or south-east, and upon them the succeeding higher members, or limestones and clays of the Jurassic series, rest. The rocks underlie and contain the Cretaceous and Ter-

[1] ὠόν, an egg, and λίθος, stone.

tiary basin of the north of France. Eastwards they occupy the Jura mountains, and flank both sides of the great Alps. They underlie the great plain of Northern Germany, but under distinct and different conditions and characters from those of either England or France. These rocks also occupy large tracts in Central Russia.

Classification of Regions.—Neumayer, in his researches into the Jurassic rocks of Europe, determines three distinct geographical regions of deposit among the Jurassic rocks in Europe :—[1]

1. "The Mediterranean province, embracing the Pyrenees, Alps, and Carpathians, with all the tracts to the south. The biological feature of this area is the great abundance of ammonites belonging to the groups *Heterophylli* (*Phylloceras*) and *Fimbriati* (*Lytoceras*).
2. "The central European province, comprising the tracts lying to the north of the Alpine ridge, including France, England, Germany, and the Baltic countries. The chief ammonites belong to the group *Aspidoceras* and *Oppellia*, and the zone is marked by abundant reefs and masses of corals.
3. "The Boreal or Russian province, comprising the middle and north of Russia, Petschora, Spitzbergen, and Greenland. In this region the groups of ammonites, *Aspidoceras* and *Oppellia*, as well as the corals, are absent, showing that in Jurassic times there was a diminution of temperature towards the north."

British Series.—The British Jurassic series are arranged in the following order and subdivisions :—

TABLE XLIX.

JURASSIC.	Upper or Portland Oolites.	Purbeckian.	Upper Fresh-water beds.	
			Middle Marine beds.	
			Lower Fresh-water beds.	
		Portlandian.	Portland Oolite.	
			Portland Sands.	
		Kimmeridgian.	Kimmeridge Clay.	
	Middle Oolite.	Corallian.	Coral Rag and Calcareous Grit.	
		Oxfordian.	Oxford Clay.	
			Kelloway Rock.	
	Lower Oolite.	Great Oolite. (Bath Oolite).	Cornbrash.	
			Bradford Clay.	
			Forest Marble.	
			Great or Bath Oolite with Stonesfield Slate.	
		Fuller's Earth.	Fuller's Earth.	
		Inferior Oolite.	Trigonia Grits.	Cheltenham Beds.
			Gryphite Grits.	
			Inferior Oolite marl.	
			Freestones.	
			Pea Grit.	
			Northampton Sands.	Dogger of Yorkshire.
	Lias.	Upper Lias Clay and Midford Sands.		
		Middle Lias, or Marlstone.		
		Lower Lias.		

[1] Jura-Studien : "Jahrb. Geol. Reichsanstalt," 1871, pp. 297, 451. "Verhandl. Geol. Reichsanst.," 1871, p. 165 ; 1872, p. 54 ; 1873, p. 288 (see "Bibliography," vol. for 1871).

Germany.—In North-west Germany the following classification of the Jurassic rocks has been adopted:—[1]

TABLE I.—*Classification of Jurassic Rocks.*

Upper or White Jura (Malm.)		Purbeck group (*Serpulit, Münder Mergel*), transition series between the Portland and Purbeck.	
		Eimbeckhäuser Plattenkalke, and Zone of *Ammonites giganteus*—the equivalent to our Portland.	
		Kimmeridge group (Upper with *Exogyra virgula*), middle or *Pteroceras* beds, Lower or Astartian with *Nerinæa* beds.	
		Oxford group (Upper or Corallian with *Cidaris florigemma*), Lower or Oxford (*Hersumer schichten*) with *Gryphea dilatata*.	
Middle or Brown Jura (Dogger).	Upper.	Clays with *Ammonites ornatus* / Shales with *A. macrocephalus*	Kelloway.
		Cornbrash with *Avicula Echinata* and *Am. posterus*.	
		Shales with *Ostrea Knorri*, and *Am. ferrugineus*.	
		Zone of *Am. Parkinsoni*, upper part of Inferior Oolite.	
	Middle.	Coronaten-schichten, clays with *Belemnites giganteus, Am. Humphriesianus, Am. Braikenridgii*; middle part of Inferior Oolite.	
	Lower.	Shales, sandstones, and ironstones, with *Am. Murchisonæ*. / Clays and shales with *Am. opalinus*.	Lower part of Inferior Oolite.
	Upper Lias.	Grey marls with *Ammonites jurensis*. / Bituminous shales (Posidonien schiefer) with *Am. Lythensis, A. communis, A. bifrons*, and *Possidonomya Bronni*.	Upper Lias.
Lower or Black Jura (Lias).	Middle.	Clays with *Ammo. spinatus*. / Marls and limestones with *Am. capricornus, A. Davæi*. / Dark clays and ferruginous marls with *Am. brevispina*.	Middle Lias.
	Lower.	Clays with *Ammo. planicosta. A. raricostatus*. / Blue grey clays with *Am. Bucklandi* [Arietenschichten]. / Dark clays with *Am. angulatus*. / Dark clays and sandy layers with *Am. planorbis*	Lower Lias.

(Credner and Geikie).

France.—The subdivisions and succession of the Jurassic rocks of Northern France are, with few exceptions, the equivalents of the English; those adopted by D'Orbigny in his "*Palæontographie Française, Terrains oolithiques*," are essentially the same, varying only through geographical differences and a few species not known in England. The following are the seven divisions of the French

[1] Heinr. Credner: "Ober. Jura in N.-W. Deutschland," 1883; Brauns' "Unter., Mittl., und Ober. Jura," 1869, 1871, 1874; Oppel's "Juraformation Englands, Frankreichs und Deutschlands," 1856; "Der Jura" (Quenstedt), 1858.

Jurassic series in ascending order. They are important to English students:—

1. BAJOCIEN.—Oolithe Inférieure, named from Bayeux; well developed in the Dept. of Calvados. In the north of France the strata are divisible into two zones, the lower characterised by *Ammonites Murchisonæ*, and the upper by *Am. Blagdeni* as in England (lowest part of Inferior Oolite of England). Six subdivisions are given by D'Orbigny—*Am. Murchisonæ*, *Belemnites giganteus*, *Pholadomya fidicula*, and *Trigonia striata*, as in England.

2. BATHONIEN or Grande Oolithe—Great Oolite Group.—The lithological zones in the North of France are calcaire à polypiers, calcaire de Ranville, oolithe de Caen, calcaire de Caen; and six Palæontological zones are recognised, partly characterised by species in Britain. In the Côte d'Or six other Faunal zones are distinguished containing British species.

3. OXFORDIEN (including Argovien and Callovien), the Oxford clay and Kelloway rock of England.—In the Côte d'Or six divisions or zones, and in the Boulonnais four subdivisions. Corresponding with Britain in the Côte d'Or are (1) the zone of *Am. Plicatilis*, (2) *Am. babeanus*, (3) *Am. biplex*, *A. canaliculatus*, *A. Henrici*, *Trigonia clavellata*, (4) *A. cordatus*, *A. perarmatus*, (5) *A. calloviensis* and *A. macrocephalus*, all British forms.

4. CORALLIEN—the *Sequanien* of some authors—is well developed in the east of France; massive limestones nearly 400 feet in thickness occur both here and in the Ardennes. In France and Switzerland the Corallien series exhibits three zones.

(a.) Upper fine white earthy Limestones, containing *Nerinæa* and *Diceras arietinum*, and absent in England.

(b.) A middle group of coral Limestones, containing as in England, *Thecosmilia*, *Thamnastræa*, *Isastræa*, *Montlivaltia* and *Stylina*, &c.

(c.) A lower or Echinoderm zone, with *Cidaris florigemma*, *Glypticus hieroglyphicus*, both of which occur in the English Coral Rag.

5. KIMMERIDGIEN.—The Kimmeridge clay, divisible into *three* zones.

3. *Virgulien*, so called from the abundance of *Exogyra* (*ostrea*) *virgula*, both in France and England.

2. *Pterocerien* (*Pteroceras oceani*), wanting in Britain.

1. *Astartien* (*Calcaires à Astartes*), Sequanian in part—*Ostrea deltoidea* and *Astarte minima* (type), both British.

6. PORTLANDIEN.—Divisible into two zones in the Côte d'Or, the upper containing *Trigonia Boloniensis* and *Pinna supra-Jurensis*. *T. Boloniensis* is not known in England, and *Pinna supra-Jurensis* is rare at Swindon and Shotover. The lower zone, as with us, contains *Ammonites gigas*. At Boulogne the beds attain a thickness of 200 feet, in which are recognised three stages, the lower being characterised by *Trigonia Micheloti*, *Cardium dissimile*, *Hemicidaris Purbeckensis?* and *Astropecten Loriolii*. (The first and second species also British.) The middle stage, with *Cardium Morinicum*, *Ostrea expansa*, *Ammonites biplex*, and *Acrosalenia Königii*, and the upper stage with *Ammo. gigas*. All but the *Acrosalenia Königii* occur in the British bed.

7. PURBECKIEN.—These beds occur conformably to the Portlandien in the Jura, near Morteau, valley of the Doubs.

The accompanying General Table of British and foreign equivalents, relative to so large a series of well-known rocks both in Britain and Continental Europe, will be useful to the student of Jurassic Geology:—

TABLE LI.—*Equivalents of the Jurassic Series, British and Foreign.*

	British Divisions.	Foreign Equivalents.
JURASSIC. LIASSIC.	1. Lower Lias.....	Terrain Sinémurien, Grès du Luxembourg, Calcaire de Valognes, Grès de Lincksfield, Gryphiten kalk, Lower Black Jura.
	2. Marlstone.....	Terrain liassien, marnes de Balingen, amaltheen-thon, numismalen mergel, Middle Black Jura.
	3. Upper Lias.....	Terrain toarcien schistes de Boll, Posidonomya Schiefer, Jurensis mergel, Opalinus thon, Upper Black Jura and Lower Brown Jura.
JURASSIC. OOLITIC.	4. Inferior Oolite...	Terrain Bajocien, Calcaire Lædonien, Calcaire à polypien, marnes Vésuliennes, Eisen-Rogenstein, discoidien mergel, Middle Brown Jura.
	5. Fuller's Earth.	Terrain Bathonien, Calcaire de Caen et Ranville.
	6. Great Oolite...	Parkinsoni bank, part of Brown Jura.
	7. Cornbrash.....	Terrain Callovien, Oxfordien Inférieur, part of Brown Jura.
	8a Kelloway.....	
	8. Oxford Clay.....	Terrain Oxfordien, Terrain argovien, Terrain à Chailles, Ornaten thon, Impressa kalke, Spongiten layer—part of Brown Jura and Lower White Jura.
	9. Coral Rag.....	Terrain Corallien, Schistes de Nattheim, Calcaire à nérinees, Middle White Jura. [The lithographic flags of Solenhofen are of this or Kimmeridge age].
	10. Kimmeridge....	Terrain Kiméridgien, argilles noirs de Honfleur, marnes du Bauné, Calcaire à Astartes; part of the Terrain Portlandien of the geologists of the Swiss Jura, who call the lower part Terrain Séquanien; part of Upper White Jura.
	11. Portland beds...	Terrain Portlandien, Upper White Jura; Upper White Jura, Calcaire à tortues de Soleure.
	12. Purbeck beds....	Purbeckien.

Relative and Local Thickness.—Although these successional groups and sub-formations give the normal *and true succession* of the Jurassic series throughout Britain, and more or less throughout Continental Europe, it by no means follows that they always rest one upon the other in any given area and have the same thickness, or are under the same physical aspects, or always contain the same fossil remains in any given section. As a rule, however, the same bed, or set of beds, traced along their strike and against or along some older shore or coast, do (under given conditions, such as depth, sedimentation, temperature, and sustenance) exhibit much the same fauna, or one special to the time of deposition and the then existing conditions. Thickness has little to do with *time deposits*, and difficulties meet us everywhere when *space* is concerned. We may illustrate this through the Inferior Oolite, which attains a maximum thickness in the Cotteswolds in the Cheltenham area, where at Cleve Cloud, Leckhampton, and the Stroud area, the series attain to the thickness of nearly 500 feet; the whole being readily divided or classified through the vertical or time distribution of certain species of Ammonites. These, however diversified the beds themselves may be through a given

horizon, are the dominant or characteristic forms, and do not pass to higher beds. The Cotteswold Inferior Oolite on reaching the coast at Burton Bradstock near Bridport, has thinned away on its strike and dip from nearly 300 feet to 10 feet, yet the three Ammonite zones remain intact, *Am. Murchisonæ* occupying the base, *A. Humphriesianus* the middle, and *A. Parkinsoni* the upper beds of the Inferior Oolite. These three Zones can be studied in the thin vertical section in the cliffs; most of the typical shells of the Cleve Cloud and Leckhampton beds (of Cheltenham) are present in each zone, and may be parted with a knife.

The following measurements will show the relative thickness of these three Zones for Gloucestershire and Dorsetshire—

Gloucestershire.		Dorsetshire.
Zone of *Ammonites Parkinsoni* . .	50 feet, reduced to	4.6
Zone of *Ammonites Humphriesianus* .	70 „ „	2.0
Zone of *Ammonites Murchisonæ* . .	158 „ „	3.6
	278	11.0

The Fuller's Earth of the Cotteswolds averages 100 feet in thickness. This, added to the Inferior Oolite (of which it is the uppermost member), would make them 378 feet in thickness. The fact of this not being represented in the Dorsetshire section, shows that in the space between the two areas, no less than 368 feet of sedimentation have been omitted or lost on the southern line of strike and dip.

Physical Features.—The Inferior Oolite of Dorsetshire, Somersetshire, and Gloucestershire, &c., and on to Lincolnshire, consists of marine limestones with occasional shales. On crossing the Humber into Yorkshire, they become chiefly massive Estuarine coal-bearing sandstones, and shales of great thickness—the whole series above the Upper Lias having been subject to no less than 7 intermittent oscillations and changes, viz., (1) the zone of *Ammonites Jurensis*, and the Dogger, *Marine;* (2) the Lower Estuarine sandstones, 280 feet thick, succeeded by depression which brought in (3) the *Marine* Millepore series, 30 to 50 feet; followed by upward movement and the deposition of (4) the middle shales and sandstones, with thin beds of coals 80 feet; succeeded by (5) another *marine* group (the Grey Limestone), rich in fossil remains 20 feet; and this Grey Limestone is followed by (6) 260 feet of Estuarine sandstones and shales rich in plants, culminating in (7) the Cornbrash, 7 feet thick. Thus, the Marine and Estuarine series alternate no less than seven times, and the Inferior Oolite group, instead of being (as in the south and south-west of England) a continuously calcareous marine deposit, is in Yorkshire a great intermarine and estuarine series, the only really calcareous portions being the Cornbrash and Millepore series.

These changes read thus—

Succession in Yorkshire.

7. Cornbrash	Marine	7 feet	thick.
6. Upper shales and sandstones	Estuarine	257	„
5. Grey limestone	Marine	20	„
4. Middle shales and sandstones	Estuarine	80	„
3. Millepore series	Marine	50	„
2. Lower shales and sandstones	Estuarine	280	„
1. Dogger	Marine	30	„
		724	„

(Then Upper Lias.)

These differences are known to occur when the Jurassic rocks of the same geological age are traced across any given area, and they tend to show us at the outset some of the physical features during deposition in the British area throughout the Jurassic period.

Before proceeding to examine the several groups separately and in detail, it is well to notice generally the broader features of the Jurassic series.

Palæontology of the Jurassic Period.

Flora.—The plant-remains handed down to us are essentially Gymnospermous, embracing the orders *Cycadeæ*, *Coniferæ*, and *Gnetaceæ*.[1] The plants or vegetation of the Devonian, Carboniferous, and Permian systems are, with the exception of a few genera of Ferns, which continue plentiful, entirely absent—

Alethopteris, *Sphænopteris*, *Tæniopteris*, and *Phlebopteris*, are some of the chief genera. The Cycads are the great feature in the Jurassic flora through species of *Cycadites* (1), *Cycadeoidea* (1), *Otozamites* (10), *Palæozamia* (9), *Pterophyllum* (7), *Zamites* (2), *Zamiostrobus* (1), and *Beania* (1)—all of which are British.

The Genera *Podozamites*, *Sphenozamites*, *Glossozamites*, *Cycadospadix*, &c., are European forms. The coniferæ are represented through *Araucarites* (5), *Pinites* (3), *Brachyphyllum* (3), and *Thuites* (5 species)[2]—all of these being British also. The shales and sandstones of the Estuarine beds of Yorkshire (Inferior Oolite), especially the middle and upper divisions, contain all the above.[3]

Faunal Value.—No formation in Britain yields so rich and varied a fauna as the Jurassic, no preceding system approaching the species in number. No less than 561 genera and 4481 species have been described, or nearly double the number known in the Carboniferous. "The conditions of sedimentation were favourable for the preservation of a succession of varied phases of marine life."

Alternation in Deposition.—The alternations of physical conditions through the British Jurassic series have been commented upon by Professor Phillips[4] in his retrospect of the Oolitic system, where

[1] The gymnosperms occupy an intermediate position between the Vascular *Cryptogams* and *Angiosperms*.

[2] The numbers refer to the specific values of the genera, or number of species in Britain.

[3] Cycads, 34 species; Coniferæ, 17 species.

[4] Geology of Oxford, Valley of the Thames, p. 293.

he dwells upon the Tripartite or Ternary arrangement of the English Jurassic strata. Phillips classifies these according to their petrographical condition, as *Calcareous*, *Arenaceous*, *Argillaceous*. These three mineral elements he thus arranges in Ternary groups :—

Petrographical Series.

Calcareous	Portland Oolite, Coralline Oolite, Cornbrash, Great Oolite, Inferior Oolite.
Arenaceous	Portland sand, Calc. grit, Hinton sand, Stonesfield Slate, Midford sands.
Argillaceous	Kimmeridge clay, Oxford clay, Bradford clay, Fuller's Earth, Upper Lias, and Lower Lias.

We have therefore marine deposits under ordinary quiet conditions, not far from shore, the materials being derived from wasting lands and organic accumulations. No fewer than five repetitions of this succession, embracing fifteen horizons, are to be traced from the top of the Lias to the close of the Portland Oolite. Such alternations point to interrupted depressions of the sea bottom or ocean-floor; these changes permitted the growth, accumulation, and preservation of various kinds of marine life in succession over the same areas.[1]

The LOWER, MIDDLE, and UPPER LIAS contain species of ammonites which essentially characterise these divisions, and even the different beds of these three horizons contain species peculiar to each, and by or through which *only* the history and sedimentation of the Lias can be understood.

Corals.—One of the chief features in the Jurassic fauna is the abundance and variety of its Corals, and the distribution of those forms which are reef-builders. Everywhere through the more calcareous beds of the Oolites the compound forms abound.[2] The chief Lias genera are *Montlivaltia*, *Thecosmilia*, *Astrocœnia*, *Cyathocœnia*, *Septastræa*, and *Isastræa*. The Inferior Oolite, in addition to those named, contains *Stylina*, *Comoseris Trochocyathus*, *Discocyathus*, *Latimeandra*, *Gonioseris*, &c. The Great Oolite group, with some Cornbrash forms (other than those occurring previously in the Inferior Oolite), are *Cyathophora*, *Convexastrea*, *Calamophyllia*, *Clausastræa*, *Microsolena*, &c. The Corallian beds have yielded other genera not in the Bathonian rocks, viz., *Rhabdophyllia*, *Protoseris*, &c.—the specific value of the whole Coral fauna being 236 species.

Echinodermata.—The Echinodermata through the whole Jurassic series reach the large number of 45 genera and 208 species. The group Echinoidea predominates, the chief genera being *Cidaris*, *Pseudodiadema*, *Acrosalenia*, *Echinobrissus*, *Pygaster* and *Pygurus*, &c.

Brachiopoda. — The Brachiopoda include 16 genera and 288

[1] Vide Phillips, *op. cit.*, p. 394.

[2] 175 species are known in Britain, ranging from the Lower Lias to the Portland Oolite. Numerically they are—Lower Lias, 13 genera and 72 species; Inferior Oolite, 19 genera and 48 species; Great Oolite, 15 genera and 38 species; Corallian beds, 10 genera and 14 species; Portland Oolite, 1 genera and 1 species.

species, this large number being chiefly distributed through the following genera:—*Terebratula* (72 species), *Waldheimia* (44 species), and *Rhynchonella* (76 species), *Spiriferina* (18 species), *Leptæna* (6 species), *Thecidium* (15 species), *Discina* (18 species), *Crania* (8 species); the remaining species are distributed through eight other genera. The two Palæozoic forms, *Spiriferina* and *Leptæna*, disappear in the Upper Lias and Inferior Oolite.

Pelecypoda.—The Pelecypoda (Lamellibranchiata) are greatly represented in the Jurassic rocks, and played an important part in the fauna of the Jurassic seas. Ninety-three genera and 1319 species range through this system. The Inferior Oolite is the richest in species, no less than 62 genera and 342 species being known in this one group of rocks. Special reference will be made to typical or illustrative genera when treating of the fauna of the geological horizons.

Gasteropoda.—The Jurassic Gasteropoda number 74 genera and 988 species, the Lower Lias, Inferior Oolite, and Great Oolite being richest, numbering respectively 226, 240, and 247 species.

Cephalopoda.—We must, however, regard the great group of the Cephalopoda as the most important element in the molluscan fauna through Jurassic time. The genus *Ammonites* alone embraces no less than 417 known species; the *Belemnites*, 112; the *Nautili*, 21; and the *Teuthidæ*, 5 species; 560 species of Tetrabranchiate and Dibranchiate Mollusca belong, and are strictly confined to, the Jurassic system, no species passing to the succeeding Cretaceous series.

The **Crustacea**, **Insecta**, **Polyzoa**, and **Rhizopoda** abound, and are, with the exception of the Carboniferous Rocks, peculiar to this system.

Pisces.—No era possesses so large a number of Fishes as the Jurassic—62 genera and 219 species, the mass of which (106 forms) occur in the Lower Lias. The most important genera are *Dapedius*, *Hybodus*, *Œchmodus*, *Acrodus*, *Lepidotus*, *Eugnathus*, *Strophodus*, and *Ischiodus*, &c.

Reptilia.—It is also through the abundance and variety of Reptilia that the Jurassic period is so significant. This age witnessed the maximum development of Reptilian types and whole orders which culminated before the close of the Jurassic age. Chelonians and Lacertilians made their first appearance during this epoch, with, also, the *Crocodilian* genera *Teleosaurus*, *Stenosaurus*, and *Goniopholis*. The most remarkable (and at the same time characteristic) extinct orders of the Reptilia are the *Ichthyopterygia* (or *Ichthyosauria*), and the *Sauropterygia* (or *Plesiosauria*), the genera *Ichthyosaurus* and *Plesiosaurus* abounding in the Lias (Lower and Upper), the Pterosauria (Ornithosauria) through the *Pterodactyles*, and Megalosaurus through the *Deinosauria*. Thus six orders of the Reptilia are represented through the Lower Mesozoic rocks, viz., the *Chelonia*, *Crocodilia*, *Ichthyopterygia*, *Sauropterygia*,[1] *Pterosauria* and *Deinosauria*. No less than 31 genera and 127 species of Reptilia range through

[1] See Table of the Distribution of the Plesiosaurs by the Rev. G. F. Whidborne: Q. Jour. Geol. Soc., 1881.

the 13 sub-divisions of the Jurassic system.[1] Some of the Pterosaurian or flying Reptiles are peculiar to Mesozoic time (ranging from the Lowest Lias to the top of the Chalk). The well-known forms of *Dimorphodon* and *Pterodactylus* from the Lias, with *Rhamphorhynchus* from the Stonesfield slates, show that these strange examples of Reptilian life were able to fly and perch or hang on the then exposed rocks, &c.[2] The most colossal beings which have ever existed at any time have belonged to the extinct order of the *Deinosauria* or *Ornithoscelida*, Reptilia in some respects intermediate in their characters between the cursorial birds and the typical Reptiles. They were exclusively Mesozoic, ranging from the Upper Triassic to the Cretaceous, but especially abounding in this age. This order underwent great development through Jurassic time; *Cetiosaurus* and *Megalosaurus* are the two chief British Jurassic genera. The European Deinosaurian fauna is large, including the Cretaceous, some 15 genera, but only a few types concern us from that stage. The *Megalosauria* of the Inferior Oolite and Stonefield Slate, as well as the *Cetiosauri* of the Great Oolite, were gigantic, being fully 50 feet in length and 10 feet in height. They are, however, surpassed in size by the discovery by Prof. Marsh in the Jurassic rocks of Colorado, of the genus *Atlantosaurus*, whose limbs dwarfed those of the gigantic *Cetiosaurus*, or the largest elephant. Prof. Marsh believes that this Deinosaur measured nearly 100 feet in length and 30 feet or more in height.[3]

Birds.—The Solenhofen limestone (lithographic stone) of the Kimmeridge horizon has yielded to us *the oldest known* bird (*Archeopteryx*). This form seems to possess some of the characters of Reptiles and also those of a true bird. The jaws carried true teeth; they possessed bi-concave vertebræ, and a long lizard-like tail, each centrum of which bore a pair of quill feathers.

Mammalia.—Three horizons in England (the Trias, Purbeck beds, and the Stonesfield Slate) have yielded the earliest forms of mammalia (marsupials)—two insectivorous genera, *Phascolotherium* and *Amphilestes*, the former being related to the American opossums; *Amphitherium* resembled the Australian *Myrmecobius* or banded ant-eater; and *Stereognathus*, believed by Professor Owen to be placental, hoofed, and herbivorous.

Towards the close of this period, or in the highest portion of the English Jurassic series, and in the middle Purbecks, we have evidence of a number of genera and species of small mammalia, all referable to the Marsupialia, and all of which "except *Plagiaulax* are Polyprotodont." Eleven genera and upwards of 20 species have been obtained, belonging to the following genera[4]:—*Triacanthodon*, *Tri-*

[1] These and their value will be discussed zoologically and in the order of time.

[2] Consult Marsh on the Pendactyles (Amer. Jour. Science, April 1882).

[3] Prof. Marsh, *loc. cit.*, vol. xxii., 1880. Seeley, Geol. Mag., Dec. 2d., vol. viii., 1881. A cast or model of the tibia of this gigantic reptile has been presented by Prof. Marsh, and is now exhibited in the British Museum, Cromwell Road.

[4] Professor Owen, "Mono. of Mesozoic Mammals," Palæontological Soc., 1871; the type species and a fine collection of these small but remarkable mammalia are in the British Museum.

conodon, *Spalacotherium*, *Amblotherium*, *Perlastes*, *Achyrodon*, *Peraspalax*, *Peramus*, *Stylodon*, *Bolodon*, and *Plagiaulax*. The last-named genus resembles the Australian kangaroo rat (*Hypsiprymnus*); Professor Owen believes that *Plagiaulax* was carnivorous, whereas the remaining genera are insectivorous; the insectivorous genera find their nearest living allies in the Australian Phalangers and the American opossum. From the Upper Jurassic rocks of North America Professor Marsh has obtained a small opossum (*Dryolestes priscus*) belonging to the Didelphidæ; this specially *American type* was differentiated within the same geographical region as that in which it now exists, the great interest being in its occurring at so early a date in that area.

CHAPTER XXXII.

GENERAL VIEW OF THE LIASSIC SYSTEM.

Range and Position.—The three divisions of the Lias constitute the argillaceous base to the overlying Calcareous and Oolitic series, resting upon the New Red marls and sandstones which constitute the great central plain of England. The eastern side of this plain is bounded by the Lias and all the higher Jurassic rocks, which exhibit marked and distinctive features in contrast to the arenaceous and argillaceous deposits to the west. The Lias presents to us the first great series of organic remains which characterise the Secondary period, illustrated by no less than 280 genera and 1830 species—not one of the forms in this large series being previously known, although they extend through 16 classes or zoological divisions. Neither the *Permian* nor the *Triassic fauna* transmitted any species beyond the limits of their sedimentation.

Geographical Distribution.—The Lias, although not so continuous over extended areas as many other formations, is nevertheless widely spread throughout Europe. Its eastern limit occurs near Vienna, and it spreads westward as far as the Vorarlberg, forming the northern slopes of the Austrian, Bavarian, and Rhætian Alps. The Lias stretches from Bâle to Coburg, and to the north-east forms part of the Swabian Alps. Würtemberg, in Southern Germany, owing to its prolific fauna, has given rise to many stratigraphical subdivisions, and the Hanoverian deposits have been worked out by Seebach,[1] Römer, Schlönbach, and others.

In France the Lias is finely shown, trending from the north-west side of the Jura mountains by Nancy on to Luxembourg.[2] The neighbourhood of Metz and Hettange has been ably worked out by Ter-

[1] "Hanoversche Jura," Berlin, 4to, 1864. Bronn: "Untere Jura im N.-W. Deutschland."

[2] *Vide* Oppel: "Die Juraformation," &c.

quem, and the Luxembourg area by Chapuis and Dewalque; while the Department of the Côte d'Or has enabled Martin to enrich his able memoir through the wealth of species occurring in the "Infra Lias" of that area. The central plateau of France is bounded on the south by numerous outlying patches towards the Rhone; and this district has been investigated by Dumortier, who, through his richly illustrated work on the Basin of the Rhone,[1] has added greatly to our palæontological knowledge of the three divisions of the Lias in the Rhone valley. Between this and the South German area, Favre has described in his "*Terrain Liassique de Savoie*" several interesting localities. Renevier and Ooster have illustrated the Swiss Lias; and Oppel has brought together or compiled the history of the Jurassic rocks of Germany, France, and England;[2] Quenstedt also in his "*Jura*" leaves little to be done, this important work absorbing in detail the history of the Jurassic fauna.[3] The Lombardian Alps yield to us, through the labours of Stoppani (and his remarkable work, "*Paléontologie Lombarde*"), a rich fauna differing from all others; whilst Renevier has worked out these beds in the Vaudois Alps, and Capellini has carefully examined the beds of this age in the Gulf of Spezzia. Eugène Eudes-Deslongchamps has rendered classic the Normandy area through his exhaustive investigations in the north of France.[4] Through these Normandy researches we become acquainted with the intimate relation that exists between the French Jurassic deposits and our own. Crossing the English Channel, the Jurassic formation reaches Britain on the coast of Dorset, and continuously ranges through England, finally disappearing at Redcar and the cliffs of Yorkshire, to pass under the German Ocean, and appear again in Northern and Central Germany. Thus, these great Anglo-French and Anglo-German Basins contain within them the complete history of the deposition or sedimentation of the Jurassic system.

Yorkshire.—The lowest division of the Lias is finely developed in Dorsetshire and Yorkshire. In the extreme north of the latter county, at Robin Hood's Bay and Redcar, the lowest beds are hidden under the German Ocean; the lowest exposed beds (zone of *Ammonites planorbis*) occur at North Cliff, near Market Weighton.

Here they measure about 40 feet in thickness, and contain a highly typical fauna, including *Ammonites planorbis, A. Johnstoni, Protocardium Philippianum, Pleuromya crowcombeia, Ostrea liassica, Avicula inæquivalvis, Modiola minima, Monotis fallax, Macrodon hettangensis, Nautilus striatus, Cidaris Edwardsii*, and *Hybodus minor*.

These *Planorbis* beds at Robin Hood's Bay occur, as mentioned, under the sea, and although seldom seen along the extended range

[1] "Études Paléontologiques sur les Dépôts Jurassiques du Bassin du Rhône." Four vols.

[2] Consult the able work by Oppel, "Die Juraformation Englands, Frankreichs, und des südwestlichen Deutschlands," Stuttgart.

[3] Quenstedt: "Der Jura," Tübingen. Also consult his "Petrafactenkunde Deutschlands," in 6 parts. Atlases, fol. Leipzig, 1849.

[4] No less than fourteen communications.

from "Cliff" through the western outcrop of the Lias, there can be no doubt of their continuity; deeper denudation in the Dales would reveal them underlying the entire area from the Humber to the Tees.

Range of the Yorkshire Lias.[1]—Whether the Lias of Yorkshire was deposited in a basin-shaped area, is by no means certain; although it is more than probable that these rocks occupy the great area defined by their western outcrop and their fully developed condition on the east, shown in the fine cliff-sections overhanging the German Ocean; where, indeed, with the exception of the lowest beds (or those below the zone of *Ammonites Bucklandi*), the entire series is exposed. Between the northern horn of the "Old Peak" and Boulby heights, all the intervening Lias is grandly shown. At Redcar, the *Angulatus* and *Bucklandi* beds constitute the "Scars;" and north of these, set in the Middle Lias (possibly visible also at low spring-tides between Staithes and Hammersea scar), the *Bucklandi* beds also again set in. The *Bucklandi* reefs, north of Robin Hood's Bay, give place to the *Middle* Lias of Hawsker Cliffs, an unexampled section exhibiting almost every known species in the Middle Lias. At Black Nab and Saltwick Nab, on to Whitby Harbour, the *Upper* Lias is the marked feature, with its rich Ammonite fauna. Continuing northwards from East Bow, and Sandsend to Kettleness, the Upper Lias still occupies the shore and cliffs; from Kettleness, through Runswick Bay and on to the Old Nab, the Ironstone series of the Middle Lias are again conspicuous. The deep inlet and valley of Staithes and all the coast to Saltburn are occupied by the Lower, Middle, and Upper Lias, exhibited in the grandest Lias cliff-sections in Britain. From Saltburn to Redcar, the Lower Lias expansively spreads out, the hard *Bucklandi* and *Angulatus* beds being at the exposed base, terminating in the Scars at Teesmouth.

Westwards of Redcar, along the western escarpments of the moorlands, the Lower and Middle Lias are fully developed and exposed, and here the Middle series reaches its maximum and (from its yield of ironstone) its highest commercial importance. It is here, too, that the Lias attains its greatest elevation above the sea in Britain (1200 feet) south of Stokesley, at Cold Moor, Whorlton Moor, Bilsdale, Moor, &c., &c. Magnificent are these western escarpments, formed by the Lias and overlying estuarine sandstones. Inliers of Lias also constitute the bases of two series of valleys of marked peculiarities. The northern and central of these vales are Westerdale, Danby Dale, Fryup, Glaisdale, and Eskdale, the waters from which drain northwards to join the Esk. The southern series of inlying masses of Lias are Bilsdale, Farndale, Bransdale, and Rosedale; all of which are drained by tributaries of the Derwent, whose waters finally fall into the Humber.

These *central inliers* are constant in their structure or stratigraphical sequence—the *lowest strata seen* being the Middle Lias, with

[1] Relative to the Lias of Yorkshire, we follow the exhaustive work of Messrs. Tate and Blake, "The Yorkshire Lias," a work which should be in the possession of all students of Jurassic geology.

its rich iron deposit surrounding each area (except Rosedale), succeeded by the Upper Lias and estuarine or Moor group. It is meteoric and river denudation alone which has revealed in these central dales and becks the corresponding features of the Upleatham, Eston, and Cleveland deposits of iron ores, &c.

The chief development of the Liassic deposits are, therefore, best seen and understood in the North Riding; that the Lias is continuous, under the covering of the estuarine Oolites and Chalk to the Humber, cannot be doubted, though only the Lower beds are clearly seen, the Upper being covered or only occasionally exposed. South of Market Weighton, at Cliff, Hotham, and Cave, and on to Brough, the Lowest Lias is exposed—though not greatly developed; the Inferior Oolite of the Lincolnshire type occurs at South Cave,[1] and is continued across the Humber, there becoming greatly expanded, and extending into Lincolnshire and Northamptonshire.

TABLE LII.—*Divisions or Stages of the Lias as adopted by d'Orbigny and French Authors.*

Upper Lias.	4. Toarcien (so named from Thouars = *Upper Lias*) in France composed of alternations of limestone and clays; in England clays, shales, and sands; may be separated palæontologically into an upper series (clays and sands), containing *Ammonites opalinus, A. Thouarsensis, A. radians, A. insignis,* and *A. variabilis*—all present in the Upper Lias of England. A middle series with *Am. bifrons,* and a lower series with *Am. serpentinus* and *A. complanatus* occur.
Middle Lias.	3. Liassien (=Middle Lias)—composed of marls and argillaceous and sandy limestones; divisible into 3, if not 4 zones, as in the Middle Lias of England. Zone 1, *Am. Margaritatus;* zone 2, *Am. spinatus;* zone 3, *Am. Davœi;* zone 4, *Am. Jamesoni.*
Lower Lias.	2. Sinémurien (=Lower Lias)—composed of argillaceous limestones and marls, and divided into the normal series of Ammonite zones—in England 7 (see Lower Lias, p. 362). 1. Hettangien (Infra-Lias)—marly and shelly limestones, with *Am. planorbis,* corresponding to our *Angulatus* and *Planorbis zones* at the base of the Lias, resting conformably upon the sandstones, marls, and bone bed of the *Avicula contorta* or Rhætic series.

Life Zones.—This division of the Lias into three stages is now acknowledged throughout Europe; and these three are again subdivided into beds or zones which are characterised by certain species of Ammonites.[2]

The Lower Lias is clearly divisible by its fossils into seven well-defined horizons or zones characterised by certain species of Ammonites. Reading upwards, they are as follows:—

[1] The Cave Oolite of Phillips.

[2] The Lower Lias into 7 zones; the Middle into 6 zones; and the Upper Lias into 10 or 11 zones.

Lower Lias.

7. *Arietites* (*Ammonites*) *raricostatus*, Ziet.
6. *Amaltheus* (*Ammonites*) *oxynotus*, Quenst.
5. *Arietites* (*Ammonites*) *obtusus*, Sow.
4. *Arietites* (*Ammonites*) *Turneri*, Sow.
3. *Arietites* (*Ammonites*) *Bucklandi*, Sow.
2. *Ægoceras* (*Ammonites*) *angulatum*, Schloth.
1. *Ægoceras* (*Ammonites*) *planorbis*, Sow.

Below the last-named zone no Ammonite has yet occurred in the British Islands. *Ægoceras planorbis*, either in shales or hard limestones, rests immediately upon beds containing *Ostrea Liassica*, the Rhætic or *Avicula contorta* series, with its ever-accompanying Bone-bed, containing remains of reptilia and fish, representing the close of the Triassic period, or the Passagé-beds between the Trias (Keuper) and Lower Lias.

Succeeding this, but physically conformable, although differing lithologically and largely palæontologically, comes the middle division of the Lias, or the "Middle Lias," a series of sandy, marly, and usually ferruginous limestones. This group of strata is also essentially characterised by Cephalopoda (Ammonites), certain forms of which hold restricted vertical range through this stage. We recognise in the Middle Lias five zones which stratigraphically succeed the zone of *Arietites raricostatus*.

The following six species of Ammonites are constant where the beds are fully developed, and constitute the recognised zonal forms, reading upwards:—

Middle Lias.

6. *Amaltheus* (*Ammonites*) *spinatus*, Brug.
5. *Amaltheus* (*Ammonites*) *margaritatus*, Montf.
4. *Ægoceras* (*Ammonites*) *Henleyi*, Sow.
3. *Amaltheus* (*Ammonites*) *ibex*, Quenst.
2. *Ægoceras* (*Ammonites*) *Jamesoni*, Sow.
1. *Ægoceras* (*Ammonites*) *armatum*.

Associated with these species there also occurs an assemblage of species of other Mollusca, which at once distinguish the Middle from the Lower and Upper Lias.

The clays, shales, and sands of the Upper Lias, when occurring in a complete section, are divided into eleven well-defined and recognisable zones. The sandy or *upper portion of* this stage, the Upper Lias sands or "Midford Sands,"[1] are chiefly characterised by the two groups, *Harpoceras* and *Lytoceras*.

In Gloucestershire and Somersetshire they include six zones, characterised by—

[1] Phillips, "Geol. of Oxford and Thames Valley," p. 118 (1871).

Upper Lias.

11. *Harpoceras* (*Ammonites*) *opalinum*, Rein.
10. *Harpoceras* (*Ammonites*) *radians*, Schloth.
9. *Harpoceras* (*Ammonites*) *Thouarsense*, d'Orb.
8. *Harpoceras* (*Ammonites*) *insigne*, Schübl.
7. *Lytoceras* (*Ammonites*) *jurense*, Ziet.
6. *Lytoceras* (*Ammonites*) *hircinum*, Schübl.

The lower portion of the Upper Lias, consisting of clays varying in consistency and colour (black in Yorkshire, dark grey in the Midland counties, and pale grey or pale brown in Somersetshire and Dorsetshire), is everywhere distinguished by—

5. *Harpoceras* (*Ammonites*) *bifrons*, Brug.
4. *Harpoceras* (*Ammonites*) *serpentinum*, Schloth.
3. *Stephanoceras* (*Ammonites*) *commune*, Sow.
2. *Stephanoceras* (*Ammonites*) *anguinum*, Rein.
1. *Stephanoceras* (*Ammonites*) *fibulatum*, Sow.[1]

The grand cliff sections of the Yorkshire coast exhibit almost every zone in all three of the above divisions, except those of *Ægoceras angulatum* and *Æ. planorbis* at Robin Hood's Bay and at Redcar, although in both localities the beds are concealed beneath the German Ocean.

Probably the most complete continuous section in Europe is comprised in the succession exhibited along the Dorsetshire coast from Pinhay Bay, west of Lyme Regis, to Burton Bradstock, east of Bridport Harbour. The shore west of Lyme Regis, Black Ven near Lyme, and Charmouth, Westhay, Golden Cap, Eype Down, &c., are, indeed, classic localities for clear demonstration of the succession of the Ammonite zones through the entire Lias formation.

"This coast section may be said to be complete from the great arenaceous deposit of Upper Lias sand, containing *Harpoceras opalinum*, with each succeeding zone of the Upper, Middle, and Lower Lias down to *Ægoceras planorbis*, and its *Ostrea* series [*O. liassica*] resting on the *Avicula contorta* beds of the Trias" near Axmouth.

[1] These 11 zones in the Upper Lias may not be seen in one vertical section, but they succeed each other through the Upper Lias in its development throughout England. In Yorkshire, Somerset, and Gloucestershire they are all determinable.

CHAPTER XXXIII.

THE LOWER LIAS.

(1) *Zone of Ammonites (Ægoceras) planorbis.*

This division of the Lower Lias is well developed in the south and west of England and South Wales from the coast section at Pinhay Bay, west of Lyme Regis, throughout the range of the Lias through England. The characteristic Ammonite occurs at the base of the Lower Lias (or in the beds between the underlying Rhætic and the richly fossiliferous *Angulatus* beds above), constituting the zone of *Ammonites planorbis*. Associated with this Ammonite are the so-called oyster beds, *O. liassica*, often termed the "*Ostrea liassica*" beds. This series at Street in Somersetshire ("Saurian Beds") yields a rich assemblage of Ichthyosauri and Plesiosauri, and may be said to commence the Reptilian Fauna of the Lias. Below these *Ostrea* and *Saurian* beds is the so-called "*white Lias*," or uppermost portion of the Rhætic series.

FAUNA.—The limestones and shaly beds contain everywhere an assemblage of Mollusca peculiar to this zone. They are *Ammonites planorbis*, *Am. Johnstoni*, *Pleuromya crowcombeia*, *Protocardium Philippianum*, *Ostrea liassica*, *Modiola minima*, *Pholadomya glabra*, *Avicula inæquivalvis*, *Macrodon Hettangensis*, and *Pecten pollux*. The sections at Lyme Regis, through Somersetshire, Penarth, Watchet, and the Bristol area, the Cliff area near North Cliff, Hotham, and Market Weighton in East Yorkshire, with the intervening exposures of the Lower Lias, reveal this zone.[1]

In North Yorkshire, the non-Ammonitiferous portion is shown near Northallerton, about 50 feet above the Black *Cassianella* (*Avicula*) *contorta* shales,—the fauna here being *Pleuromya crowcombeia*, *Ceromya infra-liassica*, *Ostrea liassica*, and *Protocardium*, &c. This zone has also been determined at the Eston and Coatham pits containing the same shells.[2]

Palæontology of the Planorbis Zone.—The fauna of the *Planorbis* Zone is nowhere rich; about 40 species are known in it. Its chief palæontological feature is the *first appearance in Britain of Ammonites*, a genus or group which in the Jurassic rocks is illustrated by 480 known species—the Lower Lias contributing 173, Middle Lias 54, and the Upper Lias 79, the species all being confined to their respective horizons.[3]

[1] The best sections of the *Planorbis zone* occur in the extensive quarries at Street in Somersetshire; the coast sections at or near Watchet and St. Audrey's Slip in Somerset; in Warwickshire, at Binton, and Wilmcote; and at Pinhay Bay and Up-Lyme in Dorset. Penarth Head in Glamorganshire finely exhibits these *Ostrea liassica* beds in the cliffs; they are seen also at Strensham in Worcestershire.

[2] See Tate and Blake: "The Yorkshire Lias;" Wright, Quar. Jour. Geol. Soc. vol. xvi.; Moore, *ib.*

[3] The lower *Saurian beds* at Street (Somerset) belong to the Zone of *A. Planorbis*, whilst the upper Saurian beds at Lyme Regis occur in the *Angulatus* and *Bucklandi* Zones.

The fauna of this zone is contained in the following list:—SAURIANS—*Ichthyosaurus intermedius, I. tenuirostris, I. communis, Plesiosaurus Hawkinsii, P. Etheridgii, P. rugosus, P. dolichodeirus,* and *P. megacephalus.* FISH—*Dapedius, Pholidophorus leptocephalus, P. Stricklandi,* AMMO. (*Ægoceras*) *planorbis,* and *Æg. Johnstoni.* ECHINODERMATA—*Hemipedina Bechei, H. Bowerbankii,* and *H. Tomesii, Pseudodiadema lobatum,* and *Cidaris Edwardsii.* CORALS—*Isastræa Murchisoni.* MOLLUSCA—*Ostrea liassica, Protocardium Philippianum, Pleuromya Crowcombeia,* and *Unicardium cardioides.*

FOREIGN CORRELATIONS.—The Planorbis beds are developed in Würtemberg and exposed near Stuttgart. In Swabia the beds are rich in Ammonites. In Baden they rest upon the Bone-bed sandstone of the Rhætic series. At Halberstadt, Dr. Dunker obtained 42 genera and 60 species from the *Planorbis* Zone. In the Department of the Côte d'Or, France, this horizon is well developed. The Lumachelle of l'Auxois, through the researches of J. J. Collenot[1] of Semur, has yielded a rich fauna, illustrating 48 genera and 120 species, added to which 40 species of Foraminifera occur, and have been described by Terquem.

(2.) *Zone of Ammonites (Ægoceras) Angulatus.*

This richly fossiliferous Zone has hitherto been incorporated with the *Bucklandi* beds, but recent research has shown that it holds, both in this country and Europe generally, a very distinctive place in the Lower Lias succession. In England and Ireland it is conspicuous, definite, and important, and distinctly underlies the Zone of *Am. Bucklandi.* The beds are not well developed in the Midland counties.

Fauna.—In Yorkshire alone 117 species have been obtained from this horizon, not including the *Rhizopoda.* At Redcar, in "the scars," the *Angulatus* series is 50 feet thick, and divisible into 35 beds.

The characteristic fossils are *Ammonites angulatus, Am. Conybeari, Cardinia Listeri, Gryphea arcuata, Unicardium cardioides, Perna infraliassica, Rhynchonella plicatissima, Plicatula liasina, Astarte Oppeli, Montlivaltia Haimei, Dentalium etalense, Terquemia arietis, Cardinia ovalis, Anomia striatula, Septastræa excavata.*

The Irish beds of this horizon have yielded 78 species. Lyme Regis, Brocastle, and Sutton in Glamorganshire, Gloucestershire, and Bath are other localities where the *Angulatus* beds are exhibited.[2] In France this Zone forms an important horizon, containing a rich and varied fauna in the Department of the Côte-d'Or; and in the Department of the Moselle M. Terquem has enumerated 180 species, and M. Martin from the Côte d'Or, 175 species.

(3) *Zone of Ammonites (Arietites) Bucklandi.*

The Lima Beds or Blue Lias of Authors.—This horizon is probably the best known of the whole Lias grouping; it forms an important subdivision of the Lower Lias, and attains great development in the Midland Counties, also in Glamorgan, Dorset, and Somerset. This zone is characterised by the Arietian Ammonites *A. Bucklandi, A. bisulcatus, A. Conybeari,* and *A. Turneri.* At Lyme Regis, and in Yorkshire, the beds have hitherto been regarded as the base of the formation. In the Midland and South-western Counties they consist of rather thick-bedded hydraulic Limestones.

[1] J. J. Collenot: "Déscription Géologique de l'Auxois," p. 209, &c.

[2] Well exposed in the extensive Harbury cutting of the Great Western Railway near Leamington.

Distribution.—These beds are exhibited in the cliffs at and west of Lyme Regis, at Stoke near Watchet, Southerndown, and Dunraven (near Bridgend), Bridgend, Keynsham, Bath, Harbury in Warwickshire, and many places near Bristol, and Red Mile in Northamptonshire, the Yorkshire Coast in Robin Hood's Bay, and Redcar. We know them also in the Hebrides, and nowhere can the Lower Lias be studied to greater advantage than in the Western Highlands, on the shores of Loch Aline, and on the eastern side of the Sound of Mull; 18 genera and 30 species have occurred in the *Bucklandi* beds of that region. These are also the *Gryphæa incurva* (*G. arcuata*), or Gryphite beds of such universal distribution, always associated with *Am. Bucklandi*, and *Lima gigantea*. *Am. Conybeari* is confined to the base, *A. Charmassei* to the lower half, *A. Sauzeanus* to the upper part, and *A. semicostatus* and *A. Turneri* to the top of the *Bucklandi* series. These divisions are admirably seen at Lyme Regis, in the 120 feet of the *Bucklandi* Limestones and shales. The Zone of *Am. Turneri* is a marked feature here on the cliffs and foreshore east of the Church. The rich ironstone of Frodingham in Lincolnshire is also worked in this Zone.[1]

Yorkshire—(*a*) **Redcar.**—The two most complete sections of the *Bucklandi* beds in Britain, are those of Lyme Regis and Redcar in North Yorkshire. The whole of the Zone at Redcar is accessible at low water, or the lowest tides; they dip west of north from 6° to 10°, and are probably under 200 feet in thickness. Messrs. Tate and Blake, both upon lithological and palæontological grounds, divide the zone into three series.

Palæontology of the Bucklandi Beds at Redcar.

(*a*) THE LOWER SERIES embraces the rocks of the "*East Flashes*" and "*Jenny Leigh's Scar*," which are black crumbling shales, about 20 feet thick. The chief fossils in the division are, *Am. Conybeari*, *Montlivaltia Haimei*, *Discohelix Oppeli*, *Monotis papyria*, and *Rhynchonella plicatissima*.

(*b*) THE MIDDLE SERIES comprises a considerable thickness of soft blue shales, with rows of small Limestone nodules, thickness nearly 100 feet. The shell banks are composed of (1) *Ostrea* or *Gryphæa arcuata* (*incurva*), with *Montlivaltia Guettardi*; (2) of *Hippopodium ponderosum*, *Cardinia concinna*, and *Lucina limbata*; (3) of *Unicardium cardioides* and *Cardinia Listeri*, while (4) a fourth bank yields oysters only.[2] The soft shales yield but few species; they are *Ammonites bisculcatus*, *Am. charmassei*, *Lima gigantæa*, and *Pleuromyæ*. The common species besides the above are, *Cryptænia solarioide*, *Cerithium gratum*, *Turritella Dunkeri*, *Hippopodium ponderosum*, *Pecten textorius*, and *Cardinia crassiuscula*.

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[1] For description and fauna of these North Lincolnshire beds, see paper by Rev. J. E. Cross, Q. Jour. Geol. Soc., vol. xxvi.

[2] Professor Blake remarks ("Yorkshire Lias," p. 55) that the shells of these banks are closely packed side by side, constituting a single layer only, and would seem to represent but one generation, the examples of each species being all about the same size; pp. 57–62 of the same work are devoted to a plan of the Redcar Rocks, and a complete and exhaustive table of the beds, giving the lithology, fossil contents, and thickness of every bed, of which there are 102, measuring 179 feet in thickness. This table is a history in itself.

(*c*) THE UPPER SERIES is composed of earthy limestones and calcareous shales about 70 feet thick, and contain in the lower portion *Cardinia Listeri, Gryphæa arcuata, Lima gigantea, L. pectinoides, Monotis inæquivalis. Belemnites acutus*, and *Ammonites Turneri*. Besides these, the upper members of this series contain *Ammonites semicostatus, Am. difformis, Am. Sauzeanus, Belemnites infundibulum, Spiriferina Walcotti*, and *Acrodus nobilis*.

The accompanying table gives the Petrology of the three divisions of the *Bucklandi* Zone, and the abundant or chief fossils therein :—

TABLE LIII.—*Showing the three Divisions of the Bucklandi Zone.*

Horizons.	Petrology.	Palæontology.
LOWER SERIES.	Black crumbling shales, covered by thin earthy shelly Limestones; 19 feet thick.	*Arietites Conybeari, Eucyclus elegans, Bissoa nana, Turbo philemon, Discohelix Oppeli, D. striata, Tancredia ovata, Plicatula liasina, Rhynchonella plicatissima, Montlivaltia, Haimei, &c.*
MIDDLE SERIES.	Soft blue shales with rows of small limestone nodules in the upper part, friable shales with shelly bands; thickness 93 feet.	*Arietites bisulcatus, Aegoceras Charmasseï, Cryptænia solairoides, Turbo solarium, Cerithium gratum, Turritella Dunkeri, Lima gigantea, Unicardium cardioides, Cardinia crassiuscula, C. concinna, C. Listeri, Hippopodium ponderosum, Gryphæa arcuata, Pecten textorius, and Montlivaltia guetturdi*
UPPER SERIES.	Earthy limestones and calcareous shales with argillaceous beds, thickness about 66 feet.	*Arietites Turneri, A. semicostatus, A. Sauzeanus, Belemnites acutus, B. infundibulum, Cardinia Listeri, Gryphæa arcuata, Lima gigantea, Pecten Thiollieri, Monotis inæquivalvis, Spiriferina Walcotti, Acrodus nobilis.*

(*b*) **Robin Hood's Bay.**—Since we select Yorkshire and Lyme Regis as our types of the *Bucklandi* Zone, it is necessary to notice the second fine exposure of the same horizon in Yorkshire, at Robin Hood's Bay, between the Old Peak and Baytown. The beds in the Bay are parallel to the shore, and sweep round the curve of the Bay. These beds are seldom exposed for lengthened examination ; the lower series is uncovered at ebb tide and the highest only at half-tide. The *Ammonites oxynotus, A. Turneri, A. obtusus*, and *A. raricostatus* series are all seen to the west of, or higher than, the *Bucklandi* beds below. About 40 feet are exhibited, but the Middle series is not reached here. The characteristic fossils in Robin Hood's Bay are *Ammonites semicostatus, Ostrea arcuata, Monotis inæquivalvis, Modiola lævis, Pecten textorius, Lucina limbata*, with large specimens of *Ammonites Turneri* or *Bucklandi*.

There are numerous other exposures of the *Bucklandi* Zone in the northern area at *Coatham, Marske Bay, Ellerbeck*, &c., showing its persistent continuity and geographical distribution. To the south of Market Weighton, or towards the Humber, between North Cave and Hotham, along the top of the range of low hills, we have full evidence of its onward presence ; thence across the Humber into Lincolnshire,

where at Frodingham this zone, although thin, is typically developed.

Comparison of the Faunas of the Angulatus and Bucklandi beds.

	Species.		Species.
The *Bucklandi* zone in Yorkshire has yielded	174,	or *minus* the Rhizopoda	138
The *Angulatus* zone " "	149	" "	113
	25		25

Of the two series the *Bucklandi* Zone has the largest fauna, both in its entire extent and as regards peculiar or special species.

(2.) **Lyme Regis.**—The *Bucklandi* Zone is admirably shown in the grand coast section at Lyme, and occupies the cliffs and foreshore between Pinhay Bay and the Church Cliffs at Lyme Regis, the so-called "Table Bed" or "Broad Ledge" forming its summit. On leaving the *Ammonites planorbis* zone, with its capping of "*Cidaris beds*,"[1] the succeeding 13 feet are occupied by the zone of *Ammonites angulatus*, which mainly consists at the base of thick beds of dark shale, interstratified with 7 beds of impure limestone. This zone also occurs under Black Ven, east of the church, *Ægoceras angulatum* being somewhat abundant there, associated with *Ægoceras moreanum*.

Fauna.—The limestones here are concretionary, with rough mammilated surfaces. *Gryphæa arcuata*, *Pecten textorius*, *Pinna Hartmanni*, *Modiola Hillana*, and *Pholadomya glabra*, with *Cidaris Edwardsii*, and *Nautilus striatus*, *Littorina* sp., and *Chemnitzia* sp., are all we know from this Zone. Immediately succeeding the thick *Angulatus* limestones, commences the rich series of the *Bucklandi* or Lima beds, here about 100 feet thick, and composed of 70 alternating beds of shale and limestone, some of the shaly beds measuring from 2 to 15 feet. These *Bucklandi* shales have yielded nearly all the Fish and Saurian remains for which this locality is famous. Twenty beds of grey semi-crystallised and earthy limestones, alternating with dark shales, comprise the whole thickness of the *Bucklandi* zone here. The more important limestone beds have local names attached to them by the workmen.[2]

Palæontology of the Lyme Regis Beds.—From this cliff-section has been obtained a fauna nearly as rich as that of Yorkshire, and in the classes Pisces and Reptilia far surpassing that of any other British locality. The following are the chief or more important species :—

Reptilia.—*Plesiosaurus macrocephalus* (type), *Ichthyosaurus communis*, *I. tenuirostris*, *I. platydon*, *Plesiosaurus Dolichodeirus*, *Ichthyosaurus intermedius*.

Pisces.—*Pholidophorus crenulatus*, *Pholidophorus* sp., *P. onychius*, *P. Bechei*, *P. latiusculus*, *P. medius*, *P. caudatus*, *P. pachycormus*, *Dapedius politus*, *D. ovalis*, *D. ornatus*, *Æchmodus Leachii*, *Eugnathus ornatus*, *Coleia antiqua*, *Hybodus speciosus*, *Chondrosteus acipenseroides*, *Myriacanthus* sp., *Acrodus* sp. (2).

[1] So called from the presence and first appearance of *Cidaris Edwardsii*, which has been recognised all through England in these lowest beds of the Lower Lias.

[2] For precise fossil-collecting, these beds and their names and succession are important.

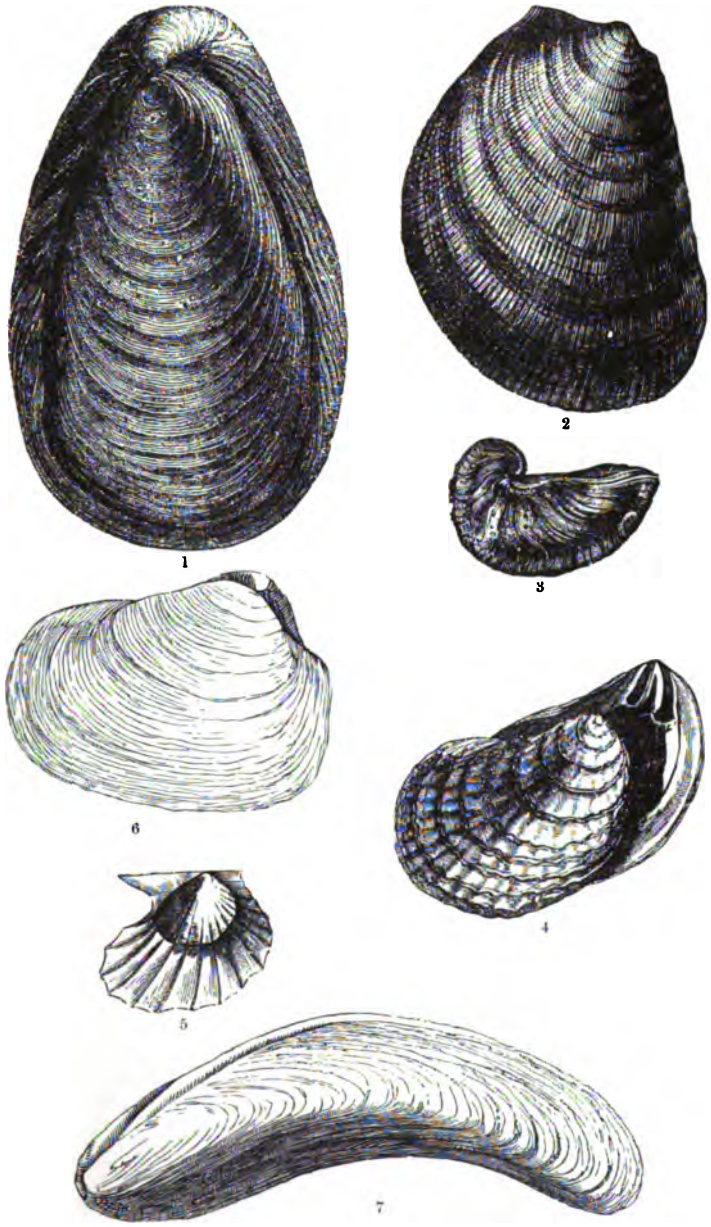
PLATE XVII.

FOSSILS OF THE LOWER AND MIDDLE LIAS.

1. *Gryphæa cymbium* (Lam.) Lower Lias.
2. *Lima gigantea* (Sow.) Lower Lias—*passim.*
3. *Gryphæa incurva* (Sow.) (*arcuata*). Lower Lias. Everywhere in the *Bucklandi* Zone.
4. *Plicatula spinosa* (Sow.) Lower and Middle Lias—*passim.*
5. *Avicula inæquivalvis* (Sow.) Lias to Kellaways Rock.
6. *Unicardium cardioides* (Phill.) Lower Lias. Yorkshire, Gloucestershire, &c.
7. *Modiola scalprum.* Middle Lias. Lyme Regis, Cheltenham.

PLATE XVII.

FOSSILS OF THE LOWER AND MIDDLE LIAS.



CEPHALOPODA.—*Arietites* (*Ammonites*) *Bucklandi*, *A. semicostatus*, *A. Turneri*, *A. Conybeari*, *A. rotiformis*, *Ægoceras* (*Am.*) *angulatus* (at base), *Nautilus lineatus*, *Geoteuthis*, *Belemnites acutus*, *B. paxillosus*.

PELECYPODA.—*Lima gigantea*, *Gryphæa arcuata*, *Lima Hermanni*, *L. antiqua*, and *Pholadomya ambigua*.

GASTEROPODA.—*Littorina ornata*.

BRACHIOPODA.—*Spiriferina Walcotti*, *Rhynchonella variabilis*.

CRINOIDEA.—*Pentacrinus tuberculatus* and *Extracrinus Briareus*,[1] &c.

The topmost bed of the *Bucklandi* Zone (termed "*Table bed*," 3 feet 6 inches in thickness), and the shales immediately below, have yielded the numerous remains of the well-known species *Ichthyosaurus platyodon*, a large series of Mollusca, and many Echinoidea; *Hemipedina*, *Pseudodiadema*, *Cidaris*, &c., occur in the shales.[2]

(3) **Gloucestershire and Somersetshire.**—The construction of the Great Western Railway between Bath and Bristol revealed, at the Saltford cutting, one of the finest sections of the *Bucklandi* series known.

The *Avicula contorta* series, about 60 feet in thickness, occurs at the base, containing the typical shells *Pecten valoniensis* and *Cassianella* (*Avicula*) *contorta* and *Pullastra arenicola*.

Chief Fossils.—The chief forms in the *Bucklandi* beds here are—

Pholodomya glabra, *Pecten textorius*, *Lima pectinoides*, *Pinna Hartmanni*, *Gryphæa arcuata*, *Arietites Bucklandi*, *A. Conybeari*, *Nautilus striatus*, *Spiriferina Walcottii*, *Rhynchonella variabilis*, *Belemnites acutus*, and *Ichthyosaurus communis*.

(4) **Glamorganshire.**—Along the coast in Glamorganshire the *Bucklandi* beds are exposed from Penarth Head to Barry Island, Aberthaw, Dunraven Castle, and to the mouth of the Ogmore, a distance of 16 miles. Along much of this coast the Lower Lias rests upon highly inclined beds of Carboniferous limestone,[3] all the intervening strata being absent. At Penarth Head the relation of the *Bucklandi* to the *Planorbis* and Rhætic (Penarth) series is complete in all details.[4]

Foreign Distribution and Fauna.—In South Germany and France the general history and fauna of this horizon are the same as in Britain, varying in no respects palæontologically. In Würtemberg the *Bucklandi* beds are developed near Stuttgart, where, as with us, they repose upon the *Angulatus* series. In Baden the Lower Lias occurs in Malsch and Oestringen in the Langeribrück Jura. In the Swabian Jura at

[1] The semi-crystalline bed in this series, termed "*Second Ledge*," is composed of the remains of this species and *Gryphæa arcuata*.

[2] The Table bed and the 18 feet of shales below may belong to the zone of *Am. Turneri*. Here the shales are filled with this Ammonite, which covers the flat shaly beds on the foreshore. *Arietites semicostatus* also occurs with *A. Turneri*.

[3] See section in Mr. Tawney's paper on the western limits of the Rhætic beds of South Wales, &c. Q. Journ. Geol. Soc., vol. xxii.

[4] For measured sections of the Rhætic series and succeeding lowest beds of the Lias, see the fine sections prepared by Messrs. Bristow, Etheridge, and Woodward, Geol. Survey Vertical Sections, sheets No. 46 and 47, illustrating the maps Nos. 18, 19, 20, 35, 36, and 44.

Küssaburg the limestones are extremely rich in the organic remains belonging to this Zone. *Ægoceras angulatum*, *Arietites Bucklandi*, *A. Conybeari*, *A. Sauzeanus*, *A. Turneri*, *A. Kridion*, and *Nautilus striatus*, with numerous other fossils identical with our own, abound.

Eastern Alps.—From the Eastern Alps, F. Ritter von Hauer describes most of the characteristic species of the *Bucklandi* Ammonites, amongst them being *Arietites rotiformis*, *A. Conybeari*, *A. bisulcatus*, *A. spiratissimus*, *A. Kridion*, *A. stellaris*, and *A. liassicus*—all recognised forms.

In Luxembourg the Lower Lias (*Bucklandi* beds) is well developed in the upper portion of the Grès de Luxembourg; the zone being rich with all the characteristic fossils.[1] They have yielded 14 species of Ammonites, 60 of Gasteropoda, 106 of Lamellibranchiata, 11 of Brachiopoda, 12 of Echinodermata, 15 of Actinozoa, 20 of Protozoa, Annelida 8, Polyzoa 6, and Crustacea 3 species. The whole fauna comprises 177 species, 60 of which are peculiar to the *Bucklandi* Zone of the Luxembourg series.

A rich assemblage of characteristic species occurs in the *Bucklandi* series of the Côte d'Or. No less than 60 species of Ammonites are there known, 16 of which are British. The whole fauna numbers 40 genera and 209 species.[2]

(4.) *Zone of Ammonites (Arietites) Turneri.*

Range.—This subdivision does not occur in Yorkshire; but although thinly developed, it is characteristically shown at several localities in the southern and central counties—Lyme Regis, the Vales of Gloucester and Warwickshire—where it forms the base of the "*Cardinia series*," in which are included all the strata of the Lower Lias between the *Turneri* and *Raricostatus* beds. In the deep cuttings in the Gloucester and Birmingham Railway, exposed at Bredon, and at Hardwick and Badgeworth, as well as at Purton, portions (not complete sections) of this Zone are exposed. It is conspicuous at Lyme Regis immediately above the thick *Lima* and *Bucklandi* series, east of the church. where it is composed of a thick solid bed of impure limestone, termed "*Broad Ledge*" or "*Table Ledge*," 3 feet 10 inches thick, which has yielded the great species *Ichthyosaurus platyodon*, also *I. intermedius* and *I. communis*, associated with *Am. Turneri*, *A. semicostatus*, and numerous specimens of *Rhynchonella variabilis*.

Immediately underlying this thick bed are 18 feet of black shales, containing large numbers of the type Ammonite. Sixteen genera and 23 species comprise the fauna, which, although small, is characteristic.

[1] The Grès de Luxembourg has been described under different names by different authors. It is the "Calcaire sableux" of Boblaye, Sauvage, and Buvignier; the "Lias *a*" of Quenstedt; the "Steininger" of Dumont; the "Unterer Lias sandstein" of Römer; the "Grès liassique" of Terquem. MM. Terquem and Piette have greatly enriched our knowledge of these beds.

[2] We give these numerical valuations for the zones, as they express their faunal history and are understood by all students.

(5.) *Zone of Ammonites (Arietites) Obtusus.*

The Vale of Gloucester yields the best inland sections and the most numerous series of fossils from this zone in the Midland counties. In the coast section at Lyme Regis, the *Obtusus* beds attain to considerable thickness—from 80 to 100 feet. They consist of beds of dark marls, which rest upon the thick "Broad Ledge"—"Table Bed,"—or top of the *Turneri Zone*. The lower part of the marls contains *Ægoceras Birchii* in nodular cement-stones; above these are bands of limestone, containing septaria, in which gigantic examples of *Arietites obtusus*, *A. stellaris*, and *A. Brookii* occur. In Gloucestershire, at Bredon, both *A. obtusus* and *A. stellaris* abound, and in Warwickshire the *obtusus* Zone forms part of the Cardinia-beds, which contain *Arietites obtusus*, *A. multicostatus*, *A. Brookii*, and *A. Sauzeanus*, from 80 to 100 feet. The remarkable Deinosaurian remains, *Scelidosaurus Harrisoni* (Owen), were found in the shales above the "mud-stones."[1]

Peculiar Fauna.—The fauna at Lyme is remarkable, a few species occurring to illustrate each genus. It is as follows:—

REPTILIA—*Ichthyosaurus platyodon*, *Scelidosaurus Harrisoni*.
FISH—*Dapedius granulatus*, *Pachycormus heterurus*, *Æchmodus Leachi*, *Lepidotus rugosus*, and *Chondrosteus crassior*.
CEPHALOPODA—*Arietites obtusus*, *A. Brookii*, *A. stellaris*, *A. Sauzeanus*, *Ægoceras planicosta*, *A. Birchii*, *Nautilus striatus*, and *Belemnites acutus*; with *Pleurotomaria similis*, *Inoceramus pinnæformis*, and *Extracrinus Briareus*. Only two species of Bivalves have yet occurred in this Zone at Lyme.

We have no evidence of the occurrence of the *Am. obtusus beds* on the Yorkshire coast, the *Bucklandi series* being there succeeded by the Zone of *Ammonites (Amaltheus) oxynotus*.

Foreign—North and South Germany.—In North Germany this series is represented near Harzburg, Liebenburg, Hildesheim, Jexheim, &c.; and in South Germany, in Swabia at the foot of the Alp, from Boll towards Randern. The northern area has yielded 30 genera and 32 species, the genera being illustrated by hardly more than one species each.[2]

(6.) *Zone of Ammonites (Amaltheus) Oxynotus.*

Compared with the rich fauna of the *Bucklandi* and *Angulatus* beds, the *Oxynotus Zone* is comparatively poor and small; the Yorkshire development in Robin Hood's bay is the largest, both as regards sedimentation and distribution of life; the Zone is rich also at Redcar and Ayton.[3] In the south of England (Lyme) the *Oxynotus*

[1] This remarkable and unique Deinosaur is now in the British Museum, Cromwell Road.
[2] *Vide* Dr. Wright, Palæontographical Soc., 1879. "Ammonites," p. 51.
[3] Messrs Tate and Blake include all the beds of the *Lower Lias* of Yorkshire above the *Bucklandi* series, in the Zone of *Ammonites oxynotus*. The succeeding Zones of *Jamesoni*, *Capricornus*, *Margaritatus*, *Spinatus*, and *Annulatus* they include in the Middle Lias.

beds constitute the greater part of the so-called "*Lias shales*," also termed the "*Belemnite beds*" from the prevalence of *B. acutus*. The Ammonites in the *Oxynotus series* may form an exception as regards poorness or poverty in species; 20 are known in Yorkshire with 5 species of Belemnites.[1] The total number of known species in this Zone is under 70, excepting the ammonites (20), which are restricted; the Lower Lias fauna, or types, appear to have decreased or migrated. *Belemnites*, *Homomya*, *Cardinia*, *Cardium*, and *Gryphæa* are the only forms which seem to attain to their maximum (*vide* Tate and Blake, "Yorkshire Lias," pp. 76–77).[2]

(7.) *Zone of Ammonites (Arietites) Raricostatus.*

Many localities in the Vale of Gloucester expose this Zone, with its marked fauna; the species occur at Marl Hill, Bredon, and Cleeve near Cheltenham. These localities have yielded the finest specimens of *Cardinia Listeri*, *Hippopodium ponderosum*, *Pleurotomaria similis*, and *Am.* (*Arietites*) *raricostatus*.

The railway cutting at Honeybourne in Warwickshire exhibits the *Raricostatus* Zone with all its characteristic species. Amongst them the Coral *Montlivaltia rugosa* and the type Ammonite (*A. raricostatus*).

At Lyme Regis the beds are composed of black pyritous impure earthy shales. The fossil contents are so impregnated with pyrites (ferric oxide) as to be most difficult of determination and preservation.

At Robin Hood's Bay in Yorkshire, this division occurs at the top of the Zone of *Am. oxynotus*, and would be incorporated with it by some observers, but the facies of the fauna and condition of deposition over an extended European area, and its position above the *Oxynotus* Zone, and below the Zone of *Ammonites Jamesoni*, claim for it special recognition; the petrology of the Zone is essentially argillaceous, the absence of limestone being a marked feature.

Fauna of the Raricostatus Zone.—The *Raricostatus* beds also occur on the north-east coast of Ireland at Ballintoy, and contain a well-marked fauna, viz.,—

Arietites raricostatus, *A. nodotianus* (*Macdonnelli*), *Ægoceras subplanicosta*, *A. armatum densinodum*, *A. muticum*, and the characteristic Belemnites (*B. acutus* and *B. penicillatus*), with the typical English bivalve shells *Hippopodium ponderosum*, *Protocardium truncatum*, *Goniomya rhombifera*, *Homomya ventricosa*, *Gryphæa obliquata*, and *Plicatula spinosa*.

This Zone at Cheltenham is defined through its Cephalopoda, especially the Ammonites, of which there are 6 species.

[1] The Zones of *Obtusus*, *Oxynotus*, and *Raricostatus* are included in one (*Oxynotus*) by Messrs Tate and Blake; hence their estimate or list of Ammonites. *Vide* "Yorkshire Lias."

[2] A measured section of the beds comprising the *Zone of Oxynotus*—having a thickness of 108 feet—is given in the "Yorkshire Lias," pp. 73–75; the characteristic fossils are inserted in their respective beds. We cannot reproduce these tables for want of space; but they are of high importance to all interested in the succession of life forms, and are repeated in the Pal. Soc. vol. for 1878 by Dr. Wright.

TABLE LIV.—*Stratigraphical Distribution of the Ammonitidæ through the Eight Zones of the Lower Lias. Dr. Wright.*[1]

Families, Genera, and Species.	Planorbis Zone.	Angulatus Zone.	Low. Bucklandi Zone.	Up. Bucklandi Zone.	Turneri Zone.	Obtusus Zone.	Oxynotus Zone.	Raricostatus Zone.
Fam. ÆGOCERATIDÆ.								
Genus ÆGOCERAS.								
Ægoceras planorbis .	+							
,, *Johnstoni* .	+	+						
,, *Liassicum* .		+						
,, *angulatum* .		+						
,, *catenatum* .		+						
,, *tortile* .		+						
,, *Charmassei* .			+					
,, *Boucaultianum*				+				
,, *Birchii* .				+				
,, *planicosta* .				+				
,, *sagittarium* .							+	
,, *gagateum* .							+	
,, *subplanicosta* .								+
Genus ARIETITES.								
Arietites Bucklandi .			+					
,, *bisulcatus* .			+					
,, *multicostatus*			+					
,, *Conybeari* .			+					
,, *rotiformis* .			+					
,, *spiratissimus*				+				
,, *obesulus* .				+				
,, *Scipionianus*				+				
,, *Sauzeanus* .				+				
,, *Crossii* .				+				
,, *semicostatus*				+				
,, *Turneri* .					+			
,, *Bonnardi* .					+			
,, *stellaris* .					+	+		
,, *obtusus* .						+		
,, *raricostatus*								+
,, *Nodotianus*								+
Fam. ARCESTIDÆ.								
Genus AMALTHEUS.								
Amaltheus oxynotus							+	
,, *Lymensis* .							+	
,, *denotatus* .							+	
,, *impendens* .							+	
,, *Simpsoni* .							+	
,, *Oppeli* . .	•						+	
	2	5	6	9	3	2	8	3

[1] Palæontographical Soc., vol. xxxiii., 1879.

Foreign.—This series is well defined in the basin of the Rhone, but M. Dumortier classes the contents with those of the *Oxynotus* group; placing the *Raricostatus* series at the summit, he attaches much importance to the Ammonitidæ, and enumerates no less than 32 species from the *Oxynotes* beds, including the *Raricostatus* fauna. The accompanying table will show that Dumortier's zone of *Am.* (*Amaltheus*) *Oxynotus* comprehends in one series the *Raricostatus*, *Oxynotus*, and *Obtusus* beds of Dr. Wright and others.[1]

1.	Couches à Ammo. raricostatus.	*Amm. raricostatus, A. planicosta, A. viticola, Cardinia philea.*
2.	Couches à Ammo. oxynotus.	*Am. oxynotus, A. aballoensis, A. Driani, A. Bonnardi, Nautilus pertextus, Avicula Sinemuriensis.*
3.	Couches à Ammo. stellaris.	*Am. stellaris, A. æduensis, A. obtusus, Gyphæa obliqua, Waldheimia cor.*
4.	Couches à Am. Davidsoni.	*Am. Davidsoni, A. lacunatus, A. Hartmanni, Pentacrinus tuberculatus.*

These four Zones (couches), according to the researches of Dumortier, do not exceed 7 feet in thickness. Nevertheless, their individuality is such as to demand from the Palæontologist clear proof of the "invariable regularity of the different horizons they occupy."

So important is the close study of the question upon the distribution of life through time and space, that no progress can be made into the history of successional horizons without careful determination of species and their stratigraphical place. It is this which lends so much importance to the labours of many of our Continental observers. The above table of the four divisions of the *Oxynotus* Zone by Dumortier, although showing that unitedly they do not exceed 7 feet, yet demonstrates their fossil contents as most significant. The important place occupied by the Ammonites in so small a vertical range also points to corresponding physical changes.

Lincolnshire.—The Lias of North-west Lincolnshire has been fully described by the Rev. J. E. Cross, the extension of railways and search for iron ores having revealed the structure of that area, and enabled us to trace the distribution and continuity of the *Bucklandi* and *Angulatus* series from Yorkshire south of the Humber.[2]

History and Palæontology of the Lincolnshire Beds.—The accompanying generalised table of the North-west Lincolnshire Lias delineates its history in the northern part of the valley of the Trent, where, in the Scunthorpe and Frodingham iron ore workings, has been obtained a rich *Lower* and *Middle Lias* Fauna. The former has yielded 28 Genera and 40 species, the latter at Scunthorpe 30 Genera and 75 species.

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[1] Études Palæontologiques sur les Dépôts Jurassiques du Bassin du Rhône, tom. ii. p. 95.

[2] Q. J. Geol. Soc., vol. xxvi. p. 115, 1875. Dr. Wright, Pal. Soc., mono., "Lias Ammonites," 1878, p 40–41.

TABLE LV.—*Fauna of the North-west Lincolnshire Lias.*

Horizons.	Petrology.	Palæontology.
Upper Lias.	Blue shale, with moulds of ammonites, of the group *Falciferi*, 60 feet thick.	*Harpoceras serpentinum, Lytoceras cornucopiæ.*
Middle Lias (Marlstone).	Hard light-grey limestone, weathering to brown ironstone, with *Rhynchonellæ*, 8 feet thick.	*Amaltheus spinatus, Avicula cygnipes, Terebratula punctata, Rhynchonella tetrahedra, Spiriferina rostrata.*
Middle Lias Marls.	Blue clay, with cement nodules, containing ammonites (*Aegoceros capricornus*) 66 feet thick.	*Aegoceras Henleyi* = *Capricornum, Belemnites paxillosus, Plicatula spinosa, Avicula inæquivalis, Nucula complanata, Lima acuticosta, Rhynchonella variabilis.*
Middle Lias Ironstone.	Pecten-bed, ironstone crowded with shells, 4 feet thick.	*Aegoceras armatum, Aeg. striatum, Belemnites elongatus, Cardium multicostatum, C. hybrida, Myacites unionides, Tancredia liassica, Pecten lævis.*
Oxynotus and Raricostatus Zones.	Blue marls of the Lower Lias, containing different zones of life, 90 feet thick.	*Aegoceras Birchii, Amaltheus oxynotus, Arietites raricostatus, Aeg. Taylori, Aeg. Loscombi, Aeg. natrix, Bel. paxillosus, B. clavatus, Gryphæa Maccullochi, Terebratula numismalis, Pinna folium, Pholadomya ambigua.*
Bucklandi Zone, Semicostatus and Upper Bucklandi bed.	Scunthorp ironstone beds, with 27 per cent. of ore, 27 feet thick.	*Arietites Bucklandi, A. Crossii, A. Conybeari, A. semicostatus. A. stellaris, Aegoceras Boucaultianum, Nautilus striatus, Belemnites acutus, Pleurotomaria anglica, Cardinia gigantea, C. crassissima, Lima antiquata, L. gigantea, L. Hettangensis, P. texturatus, Gryphæa arcuata, Hippopodium ferri, Cucullæa ovum.*
Bucklandi Zone, Lower Bucklandi beds.	Lower limestone and marl in Frodingham Railway cutting.	*Aeg. Bucklandi, Aeg. Conybeari, Aeg. semicostatus, Nautilus striatus, Bel. acutus, Cardinia Listeri, C. concinna, Pleurotomaria Anglica, Lima antiquata, Pecten textorius, Gryphæa arcuata, Lima gigantea, Pholadomya ambigua, Unicardium cardioides.*
Angulatus Zone.	Lowest Lias, Trent Valley, dark shales and clays.	*Aegoceras Liassicum, Aeg. angulatum, Nautilus striatus, Cardinia Listeri, C. concinna, Astarte obliqua, Pholadomya prima, Cardita Heberti, Modiola nitidula, Unicardium cardioides, Avicula decussata.*

The *Am. Planorbis* and *Avicula contorta*, or Rhætic beds, are absent. Keuper —red marls below—no fossils.

PLATE XVIII.

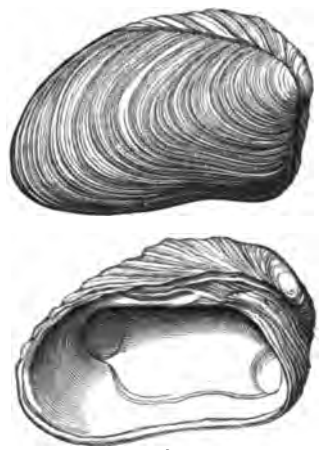
FOSSILS OF THE LOWER AND MIDDLE LIAS.

1. *Extracrinus briareus.* Lower Lias. Lyme Regis, &c. Common.
2. *Hippopodium ponderosum.* Lower Lias.
3. *Avicula cygnipes.* Lower Lias. Bristol, Yorkshire, &c.
4. *Spiriferina Walcottii.* Lower and Middle Lias. Lyme Regis, &c.
5. *Hybodus reticulatus.* Fin Spine and Tooth. Lower Lias—*passim.*
6. *Tooth of Acrodus.* Lower Lias. *Bucklandi* beds.

PLATE XVIII.

FOSSILS OF THE LOWER AND MIDDLE LIAS.

1



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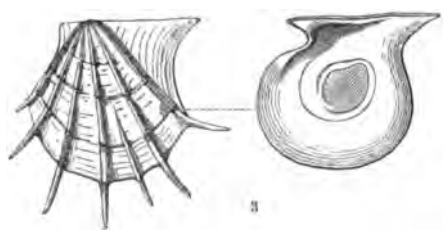
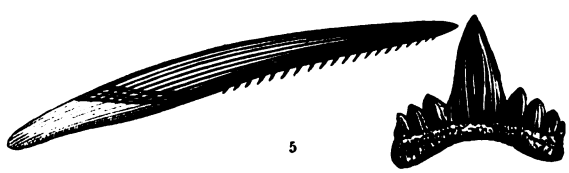


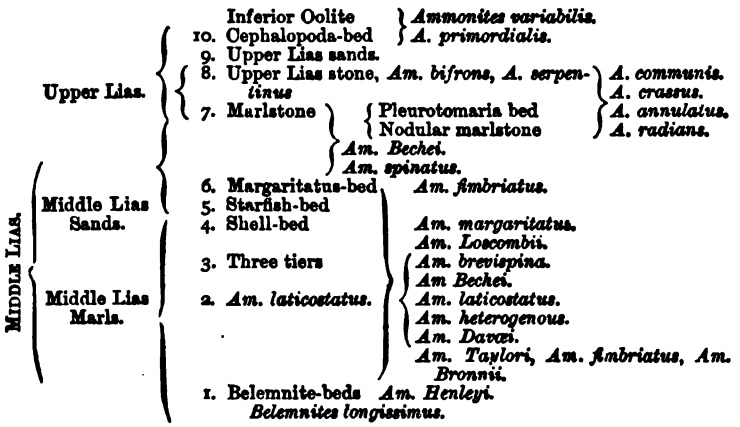
3



5

6

port Harbour—all exhibit the Middle Lias in a marked manner. At Black Ven it is 100 feet thick, *Am. laticostatus* occurring in the highest subdivision; at Westhay it measures 220 feet; at Golden Cap, near Bridport, the grey and brown sands with nodules are 70 feet thick; then follows the famous Starfish Bed with *Ophioderma Egertoni;* 160 feet of micaceous marls and layers of mudstones succeed; the so-called three tiers, 23 feet; then grey marls, containing *Ammonites laticostatus*, 100 feet, based upon the *Belemnite beds.* There are, therefore, 290 feet of grey marls capped by about 60 feet of sands, with nodules—all belonging to the Middle Lias. At Down Cliff, near Bridport, the Middle Series is 240 feet thick, with *Ammonites margaritatus.* The following is a generalised section of the Middle Lias of the Dorsetshire coast:—



Yorkshire.—The Middle division of the Lias is completely shown in Yorkshire at Hawsker Cliffs, from "North Cheek" to north of Normanby Stye Batts, or between Baytown (Robin Hood's Bay) and Whitby. Nowhere (except at Staithes) is any section comparable to this. The marlstone and ironstone series unitedly measure 138 feet, or 80 feet for the ironstone series (of which there are 16 distinct beds, with a total thickness of 7 feet), and 60 feet for the marlstone group. Compared with the richer deposits of iron ore in the districts of Eskdale, Kettleness, Staithes, and Cleveland, the ironstone beds of Hawsker Cliffs and Hawsker Bottom are too thin to be of much value economically. The characteristic shells of the Middle Lias at Hawsker Cliffs are *Pecten æquivalvis, P. sublevis, Myacites recurvus, Cardium truncatum, Dentalium giganteum, Ammonites capricornus, Am. spinatus, Belemnites—Ophioderma Milleri? Rhynchonella tetrahedra* and *Terebratula resupinata.*

Staithes.—The Middle Lias may here be examined with the greatest advantage in the cliffs at Colbourn Nab, and on the shore to the south-east of Staithes, from Old Nab to near Rosedale Wyke.

The section on the west side of Staithes Bay or at Colbourn Nab exhibits 90 feet of strata in 16 beds, the following species being characteristic, and ranging through the section:—*Ammonites spinatus, Belemnites pollex, Pecten æquivalvis, Cardium truncatum, Gryphæa cymbium, Dentalium giganteum, Modiola scalprum, Ammo. margaritatus*, &c.

The richly fossiliferous marlstone beds, which in Colbourn Nab cover the Lower Lias shale, rise with it, and contribute to the thickness and altitude of the great and unique mural faces of Boulby and Rockcliff. On these again rests the thick bed of aluminous shale of the Upper Lias, the whole surmounted by the sandstones of the Inferior Oolite (estuarine series).

In the Boulby Cliffs, therefore, occur nearly the whole of the Lias series which appear on the coast, and we are enabled to verify in one almost vertical face the following section, which (with the exception of the lowest part) embraces the whole of the Lias of Yorkshire:—

Upper Lias.	1. Cement stone beds.	*Am. bifrons, Bel. Voltzii, B. Vulgaris.*
	2. Shales and limestone and ironstone nodules.	*Am. communis, A. mulgravius, Bel. tubularis, B. triparti-tus.*
	3. Jet beds.	*Am. annulatus, Bel. cylin-dricus.*
	4. Hard shale.	
	5. Soft shale.	
Middle Lias.	6. Ironstone series.	*Am. spinatus, Bel. paxillosus, Am. margaritatus.*
	7. Marlstone series.	
Lower Lias.	8. Shales and ironstone nodules.	*Am. maculotus.*
	9. Shales and a few limestone and ironstone nodules.	*Bel. clavatus, Am. obtusus, Bel. acutus.*
	10. Limestone and shale.	*Am. Bucklandi.*
	11. Rhætic series.	*Pecten valoniensis.*

Thickness 800 feet.

The Middle Lias occupies a widely spread area (from Huntcliff and Saltburn, by Hob-Hill, Upleatham, Guisborough, and Eston, &c.), in which the Ironstone beds are extensively worked. They lie in the Zone of *Ammonites spinatus*, which possesses a fauna of 135 species, 95 occurring in the main iron seam. In the Valley of the Esk at Westerdale, Danbydale, Great and Little Fryup, and Glaisdale, this horizon and its iron beds take an important place. Again, south of the above, at Bilsdale, Bransdale, and Farndale, the upper part of the Middle Lias and its accompanying ironstone fringes the Dales, constituting one of the chief features in the escarpments of the northern ranges, overlooking the valley of the Tees.

(1) *Zone of Ammonites (Ægoceras) Jamesoni.*

General Development.—Argillaceous, micaceous, and sandy shales physically distinguish the *Jamesoni* beds from those of *Oxynotus*

below, and from the highly argillaceous clays and shales of the Zone of *Am. capricornus* above. The *Zone of Æg. Jamesoni* may be separated into two parts—the upper that of *Ægoceras Jamesoni* proper, and the lower the sub-zone of *Ægoceras armatum*, the two being equivalent to the Zones of *Ægoceras ibex* and *Jamesoni* of Oppel, and the Zone of *Æg. centaurus* of Brauns.[1]

Belemnite Beds.—The abundance of Belemnites (both in individuals and species) has given rise to the term "*Belemnite beds*," used both by French and German writers. Ten of the twenty-four known species occur in Yorkshire—*B. elegans*, *B. acuarius*, *B. charmouthensis*, *B. breviformis*, *B. aratis*, *B. virgatus*, *B. Milleri*, *B. palliatus*, *B. elongatus*, *B. clavatus*, *B. apicurvatus*, and *B. acutus*. No such assemblage occurs in any other zone.[2]

The *Jamesoni* beds in their full development are best seen in Robin Hood's Bay, where they attain to the thickness of 225 feet. The elaborate Table of the series by Messrs Tate and Blake describes each of the sixty beds and their fossil contents.[3] This Zone is well exposed in many other parts of Yorkshire, especially on the coast, in the mural faces of the cliffs.

Boulby.—The scars opposite Boulby contain *Am.* (*Lytoceras*) *fimbriatus*, which marks the upper limit of the *Jamesoni* series. "The lower 25 feet of the Boulby cliff are in this Zone, and *Ægoceras Jamesoni* is abundant in the lower 12 feet of the cliff." Between Boulby and Lofthouse Alum Works these strata attain their greatest elevation.

Huntcliff.—In the interior of the county,—*in the valleys*; only in Bilsdale has denudation excavated the area sufficiently deep to expose this Zone. (See Table in "Yorkshire Lias," p. 83.)

The two sub-zones of *Jamesoni* and *Armatus* are closely united by the occurrence of many species in common; but they have a distinct series of Ammonites.

Gloucestershire.—The deep brick-pits near Leckhampton (Cheltenham) and many localities in the county exhibit the fossils peculiar to the *Jamesoni* beds. Prof. R. Tate, in his papers on the Middle Lias of Ireland, Gloucestershire, Skye, and Raasay,[4] enters fully into the details of distribution.

Warwickshire.—The *Jamesoni* and *Ibex* beds are well exposed at Fenny Compton, the series measuring nearly 100 feet in thickness. The careful collecting and researches of Mr. T. Beesley of Banbury has given us a complete history of the *Jamesoni* beds for the central part of

[1] Messrs. Tate and Blake include the beds with *Ægoceras Henleyi* in the *Jamesoni* group, it being unaccompanied by any restricted fossils. It is an important form, and ranges extensively through England. On the Dorsetshire coast it is found in its highest development.

[2] In Swabia they are known as the "*numismalis marls*" from the prevalence of *Waldheimia* (*Terebratula*) *numismalis*.

[3] "Yorkshire Lias," pp. 79–81.

[4] "On the Middle Lias of the N. E. of Ireland"—R. Tate, Q. T. Geol. Soc., vol. xxvi. "On the Palæontology of the Junction Beds of the Lower and Middle Lias in Gloucestershire"—R. Tate, *ib.*, vol. xxvi. "On the Palæontology of Skye and Raasay"—R. Tate, *ib.*, vol. xxix.

England.[1] The assemblage of Mollusca nearly doubles that from the same horizon in Yorkshire. Their agreement and importance are shown in the following table from five localities. The Middle Lias and its Zone of *Am. Jamesoni* are well developed near Radstock, associated with *Am. Ibex* and *Am. Henleyi*.

The *Hebridean Jura*, made known through the researches of Prof. A. Geikie in 1858,[2] and added to by Prof. Judd in 1873 and 1878, has determined the presence and extension of the *Jamesoni* series in the Western Islands, where the Jurassic rocks are well developed. (See Table.)

TABLE LVI.—*Fauna of the Middle Lias in Five Localities.*

Classes.	Yorkshire.	Warwickshire (Beesley).	Gloucestershire.	Somersetshire.	Hebrides, Pabba, Scalpa, &c.[3]
Reptilia	1	1	...	...	...
Fishes	...	1	...	...	...
Cephalopoda { Ammo.	20	16	12	12	7
Cephalopoda { Bel.	7	24	6	2	5
Gasteropoda	12	28	8	18	4
Pelecypoda	45	62	24	28	28
Brachiopoda	13	16	10	14	6
Polyzoa	...	2	...	...	...
Crustacea	2	9	...	...	2
Annelida	5	9	2	...	2
Echinodermata	5	8	2	...	2
Actinozoa	...	4	...	...	...
Protozoa (Foram.)	...	28	...	...	...
	110	208	64	74	56

Foreign Correlations and Localities.—According to the researches of Dr Schlönbach,[3] the ironstones of the Middle Lias worked near Harzburg, Liebenburg, Kalcfeld, &c., are obtained from this Zone. The British species, *Aegoceras armatum*, occurs in the lowest beds; *Aeg. Jamesoni*, and its large associated fauna, in the higher strata; and the upper portion of the marls passes into beds containing *Aeg. Loscombi*, *Aeg. Valdani*, *Aeg. fimbriatum*, and *Amaltheus ibex*.[4]

[1] Beesley, Proc. of the Warwickshire Nat. Hist. and Archæol. Field Club, 1877.

[2] Geikie, Q. Jour. Geol. Soc., vol. xiv.; and Dr. Wright: "Notes on the Fossils collected by Mr. Geikie from the Lias of the Isles of Pabba, Scalpa, and Skye." Q. Jour. Geol. Soc., vol. xiv.

[3] "Ueber den Eisenstein des Mittleren Lias im Nordwestlichen Deutschland," 1863. "Zeitschr. d. Deutschen Geol. Gesellschaft," Jahrg. 1863.

[4] These are all British species. From this it would appear that the *Schichten*

North Germany.—The *Jamesoni* beds in North Germany form the base of the Middle Lias, and in part represent or are the equivalent of the *Numismalis* marl or shale of Swabia.

South-west Germany.—The *Numismalis* marls of the Middle Lias in South Germany rest upon the Lower Lias clays containing *Arietites raricostatus*. They contain *Gryphæa obliqua*, *Belemnites elongatus*, *Pecten priscus*, and *Lima Hermanni*, with *Rhynchonella tetraëdra*.

France.—The *Jamesoni* beds are developed in several departments. In the Côte d'Or, near Semur, they are divided into 4 zones,[1] each designated by a characteristic species of Ammonite in descending order, viz.—

The Zone of *Aeg. Henleyi*, Sow.
" " *Aeg. Davæi*, Sow.
" " *Aey. Venarense*, Opp.
" " *Aeg. Valdani*, D'Orb.

The Department of the Rhone.—Dumortier here shows that this division of the Middle Lias attains considerable development in the *Basin* of the Rhone. He divides the Middle Lias of that region into two great zones of unequal thickness.

a. The lower division is much developed vertically, forming the Zone of *Belemnites clavatus*, 260 feet thick.

b. The upper Zone is characterised by the occurrence of *Pecten æquivalvis*, but is not more than 25 feet thick.[2]

(2) *Zone of Ammonites Capricornus* (= *Am. Maculatus*, T. and B. and Phillips).

The beds comprised under this Zone are extremely argillaceous, differing essentially, especially so in Yorkshire, from the *Jamesoni* shales on which they rest. The range, however, of the characteristic Ammonite accords well with the differences in mineral condition of the strata. The full thickness of the *Capricornus beds* is shown on the Yorkshire coast.

1. *Robin Hood's Bay.*—The beds are 124 feet thick, and contain *Aegoceras capricornum* and *Aeg. fimbriatum* near the bottom.
2. *Rockcliff.* } thickness the same.
3. *Huntcliff.* }
4. *Colburn Nab, Staithes*[3] 78 feet.

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des Ammonites Jamesoni of Brauns include beds which form the whole of the *Ibex*-beds and part of the *Henleyi*-beds of Dr. Wright (Pal. Soc., 1879). See Brauns' "Der Mittlere Jura im Nordwestlichen Deutschland von den Posidonienschiefern bis zu den Ornatenschichten," &c. 8vo, 1869.

[1] Collenot: "Déscription Géologique de l'Auxois," p. 260, 1873.

[2] "Études Palæontologiques sur les dépôts Jurassiques du bassin du Rhône," 4 parts, 8vo, 1864-74.

[3] Messrs. Tate and Blake give 4 vertical sections—(1.) *Capricornus beds*, North Cheek, Robin Hood's Bay, 136 feet; (2.) Huntcliff, west end, 78 feet; (3.) Hammersea, near Skinningrove, 60 feet; (4.) Colbourn Nab, Staithes, 78 feet. These sections are replete with fossil remains. "Yorkshire Lias," pp. 91-97.

a. Sections along the Liassic escarpment—numerous.

b. Exposures within the Liassic inliers at Westerdale, Danbydale, Valley of the Esk (excavated for two miles in the *Capricornus* shales), *Bilsdale, Raisdale, Bransdale,* and *Farndale.*

Palæontology of the Am. Capricornus Zone.—Sixty-four species are known from the numerous *Capricornus* sections in Yorkshire.

The chief Faunal characteristics are the Ammonites and the Asteriadæ or Starfishes, the former through 6 species—*Am. capricornus, A. defossus, A. fimbriatus, A. subarmatus, A. Henleyi,* and *A. Bechei.* The Starfishes are—*Uraster carinatus, Tropidaster pectinatus, Luidia Murchisoni, Plumaster ophiuroides, Astropecten Hastingsiæ, Ophioderma Milleri, O. Gaveyi, O. carniata, Ophiolepis Murrayi,* and *O. Columba.* These mostly occur in the upper part of the fine section at Colbourn Nab, Staithes. The Pelecypoda or *Bivalves* number 20 genera and 31 species; the Gasteropoda 4 genera and 6 species; the Brachiopoda 4 species, &c., &c. We are careful to name the Tetrabranchiate Cephalopoda and Starfishes, both of which are important factors in this Zone. The Dibranchiata are Belemnites, *B. clavatas, B. apicurvatus,* and *B. elegans.*

The *Capricornus* beds occur at Mickleton Tunnel in Worcestershire. Many of the above star-fishes were obtained in the most perfect condition during the construction of the tunnel and railway.[1] The *Capricornus* series occurs in Dorsetshire, near Lyme Regis and Golden Cap.[2]

(3) *The Zone of Ammonites (Ægoceras) Henleyi.*[3]

Development.—The *Henleyi* Zone is well developed in England, and occurs beneath the "Rock bed" (when it is in place), forming the "Marlstone." A remarkable assemblage of *Asteriadæ* and *Ophiuridæ* came from these *Henleyi* or *Capricornus* beds at Mickleton Tunnel (Worcestershire) when the railway was being constructed. They occur in the same series in Gloucestershire (Cheltenham), and in the beds at Colbourn Nab, Staithes (Yorkshire). In Dorsetshire this division is conspicuous in all the cliff sections, showing the Middle Lias as at Black Ven, Stonebarrow Hill, Westhay Cliff, and Golden Cap.[4] The lower part of this fine cliff consists of—

I. The upper marls without mica—"the *Belemnite beds*" of De la Beche—containing *Belemnites longissimus, B. elongatus, B. clavatus,* which are the chief forms. *Lytoceras fimbriatum, Ægoceras Bechei, Æg. Henleyi, Æg. striatum, Phylloceras Loscombi, Nautilus semistriatus,* and *N. inornatus* are the important species of CEPHALOPODA. The GASTEROPODA are *Trochus imbricatus, Eucyclus gaudryanus, Pleurotomaria similis,* and *Cryptænia expansa;* and the PELECYPODA, *Crenatula*

[1] "On the Railway Cuttings at Mickelton Tunnel," by G. E. Gavey, F.G.S., Q. Jour. Geol. Soc. vol. ix. p. 29, 1853.

[2] The Zone of *A. capricornus* of Tate and Blake is probably the same as that of *A. Henleyi* of Dr. Wright in the Palæontographical Memoirs for 1879. Dr. Wright places the Robin Hood's Bay series in the *Henleyi* Zone, and does not notice the presence of *A. Capricornus* in the table prepared by Messrs. Tate and Blake in the "Yorkshire Lias," p. 91.

[3] Probably the *Capricornus* series of Yorkshire (Tate and Blake, "Yorkshire Lias," pp. 91-102).

[4] Consult the able paper by Mr. E. C. H. Day, "On the Middle and Upper Lias of the Dorsetshire Coast," Q. Jour. Geol. Soc., vol. xix.

(*Inoceramus*) *ventricosa*, *Hinnites tumidus*, and *Plicatula spinosa*. These upper marls are 90 feet thick, and are succeeded by the "*Three Tiers*," which are conspicuous bands in the cliff.

II. The next ascending series is the so-called well-known "*Green Ammonite beds*" or the "*Phylloceras* (*Ammo.*) *Loscombi*" series, which holds a rich collection of fossils: *Ægoceras Davœi*, *Æg. Henleyi*, *Æg. Bechei*, *Lytoceras fimbriatum*, and *Monotis* (*Avicula*) *inæquivalvis* are associated fossils.

Foreign Correlations.—The *Henleyi* (or probably the *Capricornus*) beds occur in North Germany in many areas. H. von Strombeck has described this Zone in Brunswick; Ewald, in Saxony;[1] Bornemann, in the neighbourhood of Göttingen;[2] Dr. Schlönbach at Harzburg, Oldershausen, and Markoldendorf, &c.[3] Brauns in his valuable work[4] has fully worked out the Molluscan fauna of the *Ægoceras Davœi* or *Henleyi* beds of North-West Germany, and gives a full list of their contents. Numerically summarised, they are as follows:—

CEPHALOPODA, 3 genera and 12 species; GASTEROPODA, 9 genera and 16 species; LAMELLIBRANCHIATA, 22 genera and 29 species; BRACHIOPODA, 5 genera and 12 species; ECHINODERMATA, 4 genera and 5 species; PROTOZOA (*Foraminifera*), 9 genera and 13 species—or 97 species. Most of the forms are common to Britain.

(4) *Zone of Ammonites* (*Amaltheus*) *Margaritatus.*

Development.—This division of the Middle Lias attains to great development in Yorkshire, and is fully and characteristically exhibited in the fine coast sections near Staithes, Colburn Nab, Boulby, Hawsker, Huntcliff, and also in the inliers exposed in the "Dales."[5] The Rocks comprising this Zone (or the so-called "marlstone") are, from their hardness, the cause of the peculiar terrace-like or tabulated promontories that spread out into the vales and plains occupied by the shales and clays of the Lower Lias, and which at Dumbleton, Alderton, Gretton, Churchdown (an inlier), and the Stinchcombe Hills in Gloucestershire, &c., impart such picturesque effect to the physiography of the western escarpment of the Cotteswolds; so with the north and north-west slopes and escarpments of the Yorkshire ranges and the inliers named above.

Yorkshire.—The *Margaritatus* strata attain a great development in Yorkshire, and consist of two groups. The *lower* are calcareous sandstones, and the *upper* shales, with doggers and ironstone bands. Like the underlying *Capricornus* series, the *Margaritatus* beds diminish in thickness in all directions from the area of their greatest develop-

[1] "Ueber die jurassischen Bildungen der Provinz Sachsen. Verh. d. Kön. Akad. d. Wissenschaft." Berlin, 1859.

[2] "Liasformation in der Umgegend von Göttingen," 1854.

[3] "Der Eisenstein des Mittleren Lias im N.W. Deutschland," 1863.

[4] "Der untere Jura im N.W. Deutschland," 1871. 8vo.

[5] Westerdale, Danby Dale, Fryup Dale, Glaisdale, Eskdale, Bilsdale, Bransdale, Farndale, Rosedale; these exposures, through denudation, show the universality and continuity of spread or distribution over the entire north and north-east of Yorkshire.

ment in the cliffs between Staithes and Saltburn,[1] rising with and contributing to the altitude of Boulby and Rockcliff. The *lower portion* consists of various beds of sandstone, some of which are thick, massive, false-bedded, and often ripple-marked, while others are more argillaceous or calciferous, and even arenaceous limestone. These beds are 50 feet thick at Huntcliff and Hawsker, and project from the cliffs above the Lower Lias in broad floors covered with Pectens, *Cardia*, *Dentalia*, *Aviculæ*, *Rhynchonellæ*, &c. The *upper portion* consists of sandy shales, with ironstone seams and clay-ironstone nodules imbedded in them. Lithologically, it is impossible to distinguish these beds from the overlying *Spinatus* series, and in the absence of characteristic fossils separation is impracticable. The band of ironstone known as the "*bottom seam*" or "*Avicula seam*" is the top bed of the series. This Zone differs considerably in physical development, being 62 feet thick at Hummersea, 66 feet at Staithes, and 44 feet at Hawsker.

Gloucestershire.—North of Cheltenham, at Bredon, Alderton, Dumbleton, &c., the so-called "marlstone" has been extensively worked. South of Cheltenham, the *Margaritatus* series is seen at Churchdown, Robin's Wood Hill, and Frocester Hill. The whole of the Middle Lias here measures 150 feet in thickness, and is divisible into the zones of *Jamesoni*, *Ibex*, *Henleyi*, and *Margaritatus*.

Somersetshire.—South Petherton exhibits the typical fossils of this series—*Amaltheus margaritatus* and *Amal. Englehardti* abounding. Dorsetshire contains many localities for this Middle Lias horizon.

Rutland, &c.—The Marlstone or Middle Lias in the northern part of the area exceeds 150 feet in thickness, but is reduced to less than half in the southern part, and consists of two principal members—the upper or rock bed (a mass of ferruginous limestone); the lower, a series of sandy and micaceous clays and ironstones.

Palæontology of the Margaritatus Zone.—Professor Judd divides the series into 5 groups, each especially characterised by its fossil contents. The *lowest group* (1) yields *Am. margaritatus* and *Cardium truncatum*. They are exposed in the Melton and Oakham Canal, between Edmondthorpe and Whissendine Station, and at Blaston, Loddington, and Deepdale.

2. The *second series* consists of blue micaceous clay with large septaria crowded with fossils. The chief species are *Amaltheus margaritatus* (type form), *Belemnites elongatus*, *Helicina expansa*, *Avicula inæquivalvis*, *Mytilus hippocampus*, *Modiola scalprum*, *Protocardium truncatum*, *Pleuromya uniomides*, and *Pentacrinus subangularis*.

3. Beds of blue clay with septaria, weathering red colour, and containing many of the fossils of No. 2. They are exposed at Belton, Hallaton, and Cranhoe.

4. Light blue clays, with bands of ironstone balls; usually unfossiliferous. Exposed at Oakham, Langham, and Market Harborough.

5. The Rock bed[2]—a mass of limestone, passing into good ironstone—*Rhynchonella tetrahedra*, *Terebratula punctata*, *Belemnites paxillosus*, *B. elongatus*, *Am. spinatus*, *Am. margaritatus*, *Am. communis*, *Am. annulatus*, and *Pecten æquivalvis*

[1] The lower portion of the *Margaritatus* beds has been described by Messrs. Young and Bird under the name of the "*Staithes beds*," from the coast village of that name.

[2] See p. 68, Rutland Mem., for the history of the Rock bed and its 9 divisions. This may be the Zone of *Amaltheus spinatus*. Judd, Geol. Rutland, *loc. cit.*

(fine), *P. dentatus*, *Hinnites abjectus*, and *Avicula inæquivalvis*, are the most abundant species. (*Vide* Judd, Mem. Geol. Survey, England and Wales; The Geol. of Rutland, &c., with appendix by R. Etheridge, 1875, pp. 64-78.)

Warwickshire.—The *Margaritatus* Zone is well developed near Banbury,[1] where it is believed to form the base of the Upper part of the Middle Lias. The fauna of the Banbury series is closely allied to that of Rutland, but considerably larger. At King's Sutton and Adderbury, the Ironstone beds are extensively worked in this Zone. They are the correlative deposits, in the Midland districts, of the great Ironstone deposits of Cleveland and other parts of Yorkshire.

Scotland.—The Middle Lias series above the Zone of *Ægoceras Jamesoni* are exposed in the Island of Raasay, and form a grand section on the east side of the Island. A section of 150 feet shows—

1. The *Henleyi* beds at the base.
2. The *Margaritatus* beds above; and
3. The *Spinatus* series at the top.[2]

In the cliff section, on the east coast of Skye, these same three Zones are repeated under similar petrological conditions. The *Henleyi* beds at Skye and the *Margaritatus* series in the Island of Raasay have yielded a characteristic fauna of 55 species. The *space*, or geographical distribution, and the *time*, or vertical range, of these forms of life constitute the entire value of geological formations, and at once convey to us the areas occupied by a given and associated Fauna, under special conditions of sea or land at the time of deposition. Such terms as "British and foreign," or "Continental" and "European," have no real significance beyond the fact that the life or species existing in that or this area once formed *one* series of sedimentations, extending over long periods of time—changes in physical geography having subsequently given contour and form to what we now call continent or island, &c.

Foreign Correlation.—The Zone of *Margaritatus* is widely distributed in N. Germany, and, as in Britain, is so closely united with the upper or *Spinatus* beds that of necessity they must be studied together. Von Strömbeck has described the *Amaltheenschichten*[3] in the Helmsted, Schöppensted, and Harzburg Jura, finding in them *Amaltheus margaritatus*, *A. spinatus*, *Turbo cyclostoma*, *Cryptœnia expansa*, *Inoceramus substriatus*, &c. The same species occur near Halberstadt, Hildesheim, Göttingen, Kilsmulde, showing that the upper Zones of the Middle Lias are well and characteristically developed in the North of Germany. These beds are found also in Swabia, both Professor Quenstedt and Dr. Oppel having described them, the former in his

[1] Beesley, "Sketch of the Geology of the Neighbourhood of Banbury," p. 5. 1872. Mr. Beesley has collected 80 species of Mollusca, with Upper Lias forms of ammonites, from the *Spinatus* and *Margaritatus* beds. It is difficult to realise the species on the confines of these two Zones. They have been considered as one by most palæontologists, but the Yorkshire grouping is such as to forbid their union, neither does it hold good anywhere under critical study. See also Walford: "Mid. and Up. Lias of Banbury" (Proc. Warwicksh. Nat. Hist. and Archæol. Field Club, 1878).

[2] Tate, Q. Jour. Geol. Soc., vol. xxix. 1873.

[3] Zeitschrift d. D. Geol. Gesellschaft, vol. v., Jahrg. 1883.

"*Flözgebirge Würtembergs*," and the latter in his "*Mittlere Lias Schwabens*," and also in his "*Juraformation.*" He divides the *Zone of Margaritatus* into a lower and upper series. This type species has a considerable vertical range both in Germany and France; indeed, a wide continental distribution both in time and space.

France.—At Vieux-Pont, Calvados, the *Margaritatus* beds are well exposed, and, from the description by Deslongchamps, they are the true equivalents of our English marlstone.[1]

Fauna.—The characteristic species in the "Rock-bed" are the same as our Dorsetshire series, viz. :—

Amaltheus margaritatus, A. spinatus, Pecten æquivalvis, P. disciformis, Lima punctata, Terebratula quadrifida, T. cornuta, T. punctata, T. Edwardsii, Rhynchonella acuta, R. tetraædra, and *Spiriferina rostrata.* This Zone has an extensive distribution in many Departments of France, the characteristic ammonites occurring everywhere. No less than 28 species of Ammonites, 6 species of Gasteropoda,[2] 18 of Lamellibranchiata, 8 of Brachiopoda, and 3 species of Echinodermata have been obtained by Dr. Reynès of Marseilles from the Department of the Aveyron.[3]

The large accession of species, the abundance of some, as *Protocardium truncatum, Cardita multicostata, Amaltheus margaritatus, Lima Hermanni, Monotis (avicula) cygnipes, Pecten substriatus,* and *Rhynchonella calcicosta,* and the peculiar species, as *Dentalium giganteum, Gresslya Seebachii,* and *Cardinia prototypa* readily distinguish the fauna of this Zone from that of *Am. Capricornus.* The Yorkshire Fauna from this Zone is large, being in number no less than 47 genera and 86 species, the majority of which are confined to bands more or less calcareous. On this horizon 39 species make their first appearance, the majority of which pass up to the *Am. Spinatus* beds; the peculiar or restricted species are 16.

(5.) *The Zone of Ammonites (Amaltheus) Spinatus.* (*The Ironstone Series.*)

Distribution.—The workable beds of Liassic Ironstone are in Yorkshire entirely confined to this part of the series; and it is in the north-western portion of the area that they are most completely developed, deteriorating both in quantity and quality to the south and east.

Cleveland Iron Ore.—Two bands of Ironstone are known by their finely oolitic structure :—

1. The Upper or Cleveland Main seam.
2. The Lower or Bottom seam.

The Upper seam is most extensively worked, owing to its thickness. The Lower, on account of its comparative thinness, is not worked or mined in the area of the greater development of the main seam; it, however, acquires considerable importance in the Grosmont district.

Main Seam.—The Main seam attains its greatest thickness at Eston in the north-west of Cleveland. The Rock or Ironstone is porous and Oolitic in structure, composed of carbonate of iron with certain earthy admixtures, and yields, on an average, from 30 to 32 per cent. of metallic iron.[4]

[1] "Études sur les Étages Jurassiques Infér. de la Normandie," p. 51. 1864.

[2] See Dr. Wright, "Lias Ammonites, Zone of *Maryaritatus*," Palæont. Soc., pp. 102–3, and list of French Aveyron species.

[3] Reynès, "Géologie et Palæontologie Aveyronnaises," p. 50.

[4] For detailed section of the Ironstone series at Upleatham, see Tate and

The Ironstone, after attaining its greatest thickness at Eston Nab, diminishes in quality and quantity thence in all directions. In illustration of this phenomenon, comparative sections are given by Messrs. Tate and Blake along the line of the northern outcrop. The *Spinatus-beds* at Eston consist of 15 feet of *Ironstone*, 2 feet of ferruginous shale, and 7 feet of black shelly shales, or 24 feet in all.

Sections and Range of the Zone of Amaltheus Spinatus.

Hawsker Beds.—The *Spinatus* beds are conspicuously exhibited in the wild cliffs of Hawsker Bottoms, where they measure 34 feet.

The Ironstone "doggers" are all rich in fossils, and the action of the sea has laid bare the lines of Ironstone in step-like condition, displaying the rich fauna through almost every bed. The *Spinatus* series here numbers seventeen beds, ranging between the Zone of *Am. Annulatus* above and the *Margaritatus* shales below.

Fauna.—The characteristic species here are:—*Pecten æquivalvis, Pleuromya rostrata, Modiola scalprum, Monotis inæquivalvis, Unicardium subglobosum, Dentalium elongatum, Pholadomya ambigua, Gryphæa cymbium, Arcomya arcacea, Amaltheus spinatus, Am. solitarius, Belemnites breviformis, Cryptænia expansa, Chemnitzia*, and *Turbo cyclostoma.*

Kettleness.—The *Spinatus* series here forms the base of the cliff, the main seam occurring above high-water mark as a low mural terrace about 300 yards in length.[1] The fauna is the same as at Hawsker Cliffs.

On approaching "Old Nab," the Main seam and the Ironstone series, from the *bottom stone* upwards, constitute a low, conspicuous, and long, cliff-like terrace, partially submerged at high tide.

Old Nab.—The section at Old Nab, like that of Kettleness and Hawsker, contains a rich assemblage of Mollusca. Colborn Nab, through the fault, exposes the sandy beds of the *Margaritatus* series.

The Cephalopoda are characteristically different in the various sets of strata; in descending order we find:—

1. That *Ammonites annulatus* occurs above the Ironstone.
2. „ „ *spinatus* „ in the Ironstone.
3. „ „ *margaritatus* occurs in the Marlstone.
4. „ „ *maculatus* „ below the Marlstone.

The thickest section of the *Spinatus* beds is at Skelton Beck, Saltburn, where they attain 92 feet, replete with organic remains of the same species as before.

Inliers.—These are, geographically, the same as the *Margaritatus* group, occupying the central dales.

Blake, "Yorkshire Lias," pp. 119, 120. The information given under the Zone of *A. Spinatus* is of the utmost value stratigraphically and economically, pp. 119–156; it is too extensive for analysis here.

[1] These are "*the Kettleness beds*" of Messrs. Young and Bird in their "Yorkshire Coast."

The Grosmont Series near Whitby, in the Vale of the Eske, are nearly 60 feet thick, and exhibit a remarkably large fauna. The Ironstone seams worked here are called the "*Pecten Seams*," of which there are three, all yielding *Pecten æquivalvis*, the characteristic shell of the series.

The fossils of the Main seam are most numerous, both as regards species and individuals; they are almost entirely confined to the Oolitic portion, and also chiefly to the upper part of the seam. Many of the bivalves are found with their valves in apposition; these include the Myacidæ (*Pholadomya*, *Pleuromya*, *Gresslya*, *Arcomya*, and *Ceromya*), the majority of which were probably, like their living congeners, burrowers in the Limestone ooze.

Characteristic Species of the Main Seam.—One hundred species have been obtained from the Zone of *Am. spinatus* in Yorkshire, ninety-five of which occur in the Cleveland Main Iron Seam. The most common species are: — *Am. spinatus*, *Belemnites breviformis*, *B. paxillosus*, *Cryptænia consobrina*, *Ostrea submargaritacea*, *Pholadomya ambigua*, *Astarte striato-sulcata*, *Pecten æquivalvis*, *P. lunularis*, *Monotis cygnipes*, *Macrodon liasinus*, *Gresslya intermedia*, *Pleuromya rostrata*, *Arcomya arcacea*, *Rhynchonella capitula*, *R. tetraedra*, *R. lineata*, and *Terebratula punctata*.

Dorsetshire.—At Down Cliffs near Bridport Harbour, the *Spinatus* beds form the uppermost portion of the "micaceous marls" of De la Beche.[1] The true character of the junction beds of the *Spinatus* Zone with the overlying and succeeding *Communis* series, is rendered clear and definite through the researches of Mr. E. H. Day,[2] and the sections constructed by the present writer, through the whole series along the Dorsetshire Coast, from the Rhætic beds of Pinhay Bay to Bridport Harbour.

The *Spinatus* Zone at Down Cliffs by Toad's Cove is between 80 and 90 feet thick, the upper portion being in dark-grey sandy micaceous marl, 18 feet, and containing *Am. Spinatus* and *Belemnites breviformis*. Immediately below this are large blocks of indurated sandstone about 8 feet thick, the base of the Zone being in light-brown micaceous sands, which are between 50 and 60 feet thick. The *Margaritatus* Zone below measures more than 100 feet, resting upon the beds containing *Am. capricornus*, which constitute the base of the Down Cliffs, and in which occur *Am. capricornus*, *Am. Henleyi*, *Am. Bechei*, and *Am. Davœi*. The key to the structure of these cliffs is the successional evidence afforded by the Ammonitidæ, and while we adopt the five most significant species as *types*,[3] other species which are equally important, and associated with the types, tell the same tale. Thus at Down Cliffs near Bridport we have—

[1] Geol. Trans., 2d ser., vol. ii. t. 3.
[2] Quart. Jour. Geol. Soc., vol. xix.
[3] Now received throughout Europe.

Upper Lias.	The Zone of *Am. Jurensis.* 70 feet thick.	Associated with *Am. opalinus.*
	Zone of *Am. communis.* 75 feet thick.	*Am. serpentinus, Am. communis, Am. bifrons, Am. Raquineanus.*
Middle Lias.	The Zone of *Am. spinatus.* 82 feet thick.	*Am. spinatus, Belemnites breviformis.*
	The Zone of *Am. margaritatus.* 103 feet thick.	*Am. margaritatus, Am. fimbriatus, Belemnites elongatus, Pleuromya anglica, P. unionides, Pecten æquivalvis, Lima Hermanni, Pinna Hartmanni,* and *Gryphæa gigantea. Ophioderma Egertoni, Pentacrinus subangularis.*
	The Zone of *Am. capricornus.* 76 feet thick.	*Am. capricornus. Am. Henleyi, Am. Beckei, Am. Davœi.*

The coast cliffs to the west contain the remaining well-determined horizons or zones through the entire Lower Lias, down to the Rhætic series.[1]

Gloucestershire.—There are localities in the Cotteswold Hills where the *Spinatus* beds appear, but at no spot or in no locality have they been so carefully worked out as at Churchdown near Gloucester, owing to the constant research of the Rev. F. Smithe.[2] This hill of circumdenundation is an outlier of the Cotteswold, and consequently an example or corresponding part of the adjacent hill country. The Middle Lias of Churchdown is a typical relic of the strata that once stretched across the Vale of Gloucester in certain directions as far as the eye can reach. In the geological structure of Churchdown all the stages but the Jurensis or Midford sands are present, each zone or phase of Lias life being represented. A thorough examination of the North Gloucestershire Middle Lias brings out the fact that the study of the beds, through correlation, directly supports the view which postulates the existence of a *Spinatus* Zone. The Churchdown sands and associated marly or argillaceous portion were laid down or sedimented with little or no interruption, and were well adapted to receive and transmit the representative forms of life of the Middle Lias period. The difference between the Petrology of the Zones of *Spinatus* and *Margaritatus* is marked and certain, as much so as the difference in their Palæontology or Fauna, and the assemblage of life in this one locality may be taken as a type of the same rocks, for the western escarpment of the Cotteswold range. They supply a connecting link between the prolific series of the south coast and those deposits equally rich in Yorkshire, not omitting on their strike the Middle Lias deposits and the *Spinatus* beds of North-West Lincolnshire.[3]

[1] Mr. Day's paper (*loc. cit.*) is replete with all details relative to the Middle Lias of the Dorsetshire Coast.

[2] On the Middle Lias of North Gloucestershire, the *Spinatus* Zone, by the Rev. F. Smithe (Trans. Cotteswold Club, vol. for 1880.)

[3] See "Geology of North-West Lincolnshire," by the Rev. J. E. Cross. Quart. Jour. Geol. Soc., vol. xxi., 1875.

Palæontology of Middle Lias in Gloucestershire.—A complete list of the Fauna of the Ammonites (*Amaltheus*) *Spinatus* Zone in Gloucestershire has been prepared by the Rev. F. Smithe (*loc. cit.*) It is given numerically in the following tabular statement, from which we find that 72 genera and 144 species occur in the *Spinatus* Zone in Gloucestershire:—

Classes.	Genera.	Species.
Plantæ	5	5
Brachiopoda	4	20
Conchifera	30	66
Gasteropoda	9	10
Belemnites	1	9
Teuthis	1	1
Ammonitidæ	7	11
Nautili	1	3
Echinodermata	4	9
Annelida	4	4
Crustacea	6	6
	72	144

The most abundant and characteristic species are *Amaltheus spinatus, Harpoceras Normanianum, H. ægion, H. Thouarsense, Lytoceras lineatum, Belemnites Paxillosus, B. breviformis, B. brevis, Turbo paludinæformis, Protocardia truncata, Ostrea cymbium, Pholadomya obliquata, Avicula inæquivalvis, Plicatula spinosa, Pecten æquivalvis, Harpax Parkinsoni, Pecten priscus, Lima Hermanni, Gresslya ovata, Terebratula punctata, Waldheimia resupinata, W. numismalis, Rhynchonella variabilis,* and *R. acuta.*

Scotland.—In the Western Isles of North Britain, as well as on the eastern coast, are remains of the Middle Lias, which testify to the archipelagic character of the North Jurassic sea.

Of the Jurassic rocks of the Western Isles (Skye and Raasay) we have nearly a complete account from Dr. Bryce;[1] and the isles of Pabba, Scalpa, and Skye, through the researches of Professor A. Geikie and Dr. Wright (in 1857), show how rich in these northern regions was the fauna of the Middle Lias sea, only a fragment of which can we now recognise.[2]

On the east coast at Dunrobin, the Middle Lias has been satisfactorily determined, the thickness of the series being about 80 feet. The clay beds have yielded a considerable fauna, leaving no doubt as to their age; 23 genera and 35 species are recorded.[3] The *Spinatus Zone* is hardly reached at Dunrobin.

Foreign Deposits and Equivalents.—The *Spinatus* beds occur in

[1] Dr. Bryce: "On the Jurassic Rocks of Skye and Raasay," Quart. Jour. Geol. Soc., vol. xxix. p. 317, &c.

[2] Dr. Wright: "Notes on the Fossil Collection made by Mr. Geikie from the Lias of the Isles of Pabba, Scalpa, and Skye," Quart. Jour. Geol. Soc., vol. xiv. 1858.

[3] Prof. Judd: "On the Secondary Rocks of Scotland" (first paper), Quart. Jour. Geol. Soc., vol. xxix., 1873. *Ib.*: "On the Western Coasts of Scotland" (second paper), Quart. Jour. Geol. Soc., vol. xxxiv. pp. 660–743. 1878.

the Department of the Moselle, of the Meurthe, near Gundershofen on the Lower Rhine, in the Department of the Côte d'Or, and at Lozère at Abeyron. Oppel, in his "*Juraformation*," describes the grouping for Würtemberg and Northern Franconia, in Bavaria. In the former, 17 *representative species* occur in the *Spinatus* beds, and 18 in the *Upper Margaritatus* series.

The Middle Lias fauna of Markoldendorf has been described by Dr. A. Römer in his "*Versteinerungen des Norddeutschen Oolithengebirges.*"[1] In this basin the two Zones are well defined. The lower or *Capricornus*, which is rich in ironstone and oolitic in structure, yields a characteristic fauna. The upper or *Spinatus* Zone petrologically resembles these Middle Lias beds of Gloucestershire, through ferruginous concretions, composed of "*Sphærosiderites*" or carbonate of iron.[2] Schlönbach describes exposures of Middle Lias at Liebenburg near Goslar (see section, p. 488 *et seq.*)[3] These same strata occur at Altdorf in Bavaria, on both sides of the Danube, where they are extensive and characteristic, the chief fossils occurring in Geodes.

The accompanying table shows the numerical fauna of the Zones of *Margaritatus* and *Spinatus* for Yorkshire, Gloucestershire, and Scotland:—

TABLE LVII.—*Fauna of the Margaritatus and Spinatus Zones.*

Classes.	Margaritatus Zone.			Spinatus Zone.		
	Yorkshire.	Gloucestershire.	Scotland.	Yorkshire.	Gloucestershire.	Scotland.
Reptilia	1	1	...	2	1	...
Fish	...	...	...	...	...	...
Ammonites	5	4	1	6	11	2
Nautili	...	2	...	...	2	...
Belemnites	6	2	3	10	10	4
Gasteropoda	14	7	2	24	24	1
Pelecypoda	46	26	17	63	62	10
Brachiopoda	7	8	7	11	20	4
Polyzoa	...	...	...	...	...	...
Crustacea	1	...	1	...	6	...
Annelida	2	...	...	4	4	1
Echinodermata	5	6	1	3	9	1
Actinozoa	..	...	...	...	...	...
Protozoa	...	...	...	...	...	...
Plantæ	...	...	...	2	5	...
	87	56	32	125	154	23

[1] This series occurs between Markoldendorf and Einbeck, on the river Ilm, 40 miles south of Hanover; sedimentation here was slow and fine.

[2] *Sphærosideriten chalybites*, or Spathose iron.

[3] Section of Middle Lias Eisenstein, Liebenburg, where the fauna of the beds is the same as our own.

The following table also shows the distribution of the Middle Lias Ammonites through the recognised six Zones, and the distinctive range of each species, three only (*Phylloceras Loscombi, P. zetes*, and *Lytoceras fimbriatum*) occurring in two Zones or horizons:—

TABLE LVIII.—*Distribution of the Ammonites of the Middle Lias of the British Islands through the Six Zones. Prepared by Dr. Wright.*[1]

Families, Genera, and Species.	Armatus.	Jamesoni.	Ibex.	Henleyi.	Margaritatus.	Spinatus.
Fam. ÆGOCERATIDÆ.						
Genus ÆGOCERAS.						
Ægoceras armatum	+					
,, *densinodum*	+					
,, *submuticum*	+					
,, *Jamesoni*		+				
,, *brevispinum*		+				
,, *Taylori*		+				
,, *pettos*		+				
,, *Valdani*			+			
,, *maugenisti*			+			
,, *Henleyi*				+		
,, *striatum*				+		
,, *Becheri*				+		
,, *curvicornum*				+		
,, *Davœi*				+		
Fam. ARCESTIDÆ.						
Genus AMALTHEUS.						
Amaltheus Ibex			+			
,, *margaritatus*					+	
,, *Engelhardti*					+	
,, *spinatus*						+
Fam. LYTOCERATIDÆ.						
Genus PHYLLOCERAS.						
Phylloceras Loscombi			+	+		
,, *Zetes*					+	+
Genus LYTOCERAS.						
Lytoceras fimbriatum			+	+	+	
,, *lineatum*				+		
	3	4	5	8	4	2

[1] Palæontographical Soc., vol. xxxiii., 1879.

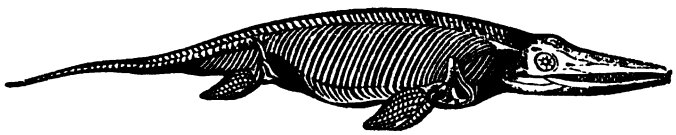
PLATE XIX.

FOSSILS OF THE LOWER AND MIDDLE LIAS.

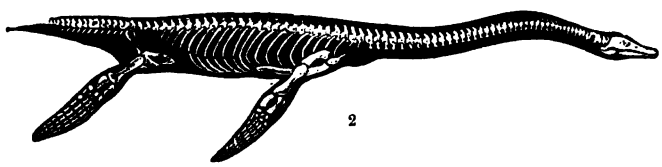
1. *Ichthyosaurus communis* (Conyb.) Order *Ichthyopterygia*, Owen (=*Ichthyosauria*, Huxley). Lower Lias. Lyme Regis, Barrow-on-Soar, Street, &c.
2. *Plesiosaurus dolichodeirus* (Conyb.) Order *Sauropterygia*, Owen (=*Plesiosauria*, Huxley). Lower Lias. Lyme Regis, Watchet.
3. *Ophioderma Milleri* (Phill.) Middle Lias. Staithes, Yorkshire.
4. *Ophioderma Egertoni* (Broderip). Middle Lias. Golden Cap, near Charmouth.

PLATE XIX.

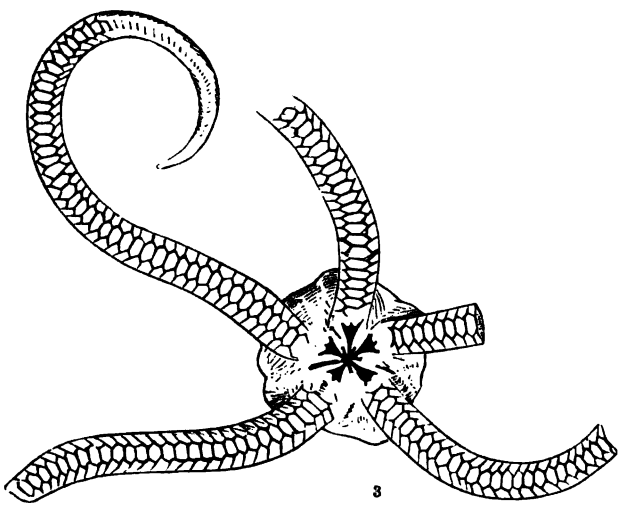
FOSSILS OF THE LOWER AND MIDDLE LIAS.



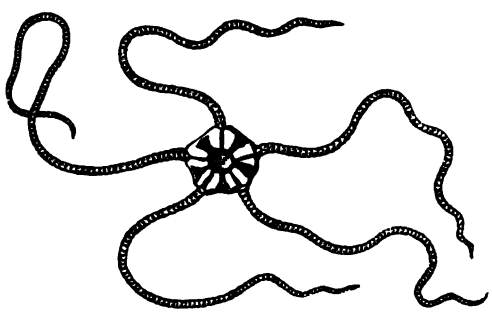
1



2



3



4

CHAPTER XXXV.

UPPER LIAS.

Stratigraphical Position.—We include in the Upper Lias all the argillaceous, shaly, laminated, marly, and sandy deposits that are interposed between the *Am. Spinatus* beds of the Middle Lias and the basement beds of the Inferior oolite, containing *Ammonites* (*Harpoceras*) *Murchisonæ*.[1] This group of strata nearly corresponds to the "*Posidonienschiefer mit stinksteinen*" of Quenstedt.

The Upper Lias varies greatly in thickness through the Midland counties, measuring in some places 300 feet. In South Lincolnshire it attains 200 feet, thinning away entirely in S. Yorkshire, whilst in N. E. Yorkshire it again thickens out, and forms on the coast some fine and conspicuous sections.

Sectional Divisions.—In *Rutlandshire* its thickness is about 200 feet, and it consists almost entirely of clays, and is divisible into five sections. In ascending series they occur as follows[2]:—

a. *Thin paper shales with fish*, &c.—Finely laminated grey shales, with bands of flat nodules composed of argillaceous limestone. These shales occur at Allexton, Barleythorpe, and Edmondthorpe, &c. They extend southwards into Gloucestershire and Somersetshire. *Inoceramus dubius* is one of the most characteristic shells.

b. *Serpentinus beds.*—These succeed the shales, but consist of clays with nodular layers of Limestone. This Zone is crowded with ammonites belonging to the group of the *Falciferi*,[3] such as *Am. serpentinus*, *A. falcifer*, *A. Lythensis*, *A. elegans*, *A. concavus*, *A. radians*.

c. *Communis beds.*—Beds with ammonites of the group Planulati succeed the serpentinus shales wherever sections are opened. The species are *Am.* (*Stephanoceras*) *communis*, *S. annulatus*, and *S. crassum*.

d. The middle portion of the Upper Lias clay often contains pyrites and jet, and weathers into selenite. Fossils are rare in this division, which in Rutland is 100 feet thick.

e. *Leda ovum beds.*—The highest beds of the Upper Lias are septariform, and everywhere distinguished by the abundance of *Leda ovum*. This shell is equally abundant in the upper or alum shells, &c., of the Yorkshire coast. The prevailing ammonite is *Harpoceras*

[1] The authors of the "Yorkshire Lias" make the hard grey shales with *Am. annulatus*, the top of their Middle Lias, on Petrological as well as on Palæontological grounds.

[2] *Vide* Prof. Judd, Mem Geol. Survey. Geol. of Rutland, pp. 79-89.

[3] The *Falciferi* are as entirely confined to the *Upper Lias*, as the group *Arietes* is to the *Lower Lias*. Besides the above species in the group Falciferi, *A. insignis*, *A. striatulum*, *A. Levisoni*, *A. opalinus*, *A. subradiatus* are Upper Lias species also.

bifrons. The Planulati are also numerous, and are represented by *Stephanoceras commune, S. annulatum, S. crassum, S. fibulatum, Am. (phylloceras) heterophyllus.* Belemnites—*Myacites donaciforme, Arca truncata*, and *Discina reflexa*. These beds are well exposed at Manton, Stamford, Gretton, and Pilton, &c., in the county of Rutland,[1] and also along the coast, and inland section in Yorkshire, and everywhere below the Northamptonshire iron-ore beds in that county.

Lincolnshire.—The Upper Lias in Lincolnshire near Stainby is 200 feet thick, but is reduced to 60 feet north of Grantham and Lincoln. Everywhere it comprises the western or scarped slope of the "cliff," spreading into the plain to the west.

Dorsetshire.—At Golden Cap and Down Cliffs the sands and clays are 70 feet thick, and contain a fine suite of Upper Lias fossils.

Somersetshire.—Although thinly developed in Somerset, the Upper Lias nevertheless presents many features of Palæontological interest. At Ilminster it has yielded a large fauna, chiefly through the investigations of Mr. Charles Moore. The Reptilia, through the Teleosauri and Ichthyosauri, as well as the two families of fishes, Lepidoti and Pachycormi, are in the finest preservation. The Upper Lias is well seen at Glastonbury Tor and Brent Knoll; in the Upper Lias escarpments between Yeovil and Bath, *A. bifrons, A. communis, A. crassus*, and *A. annulatus*, occur in nearly all sections. Lithologically, the Somersetshire beds differ from those of Rutland, Lincoln, and Yorkshire.

Gloucestershire.—The Upper Lias, in its continuity from Somersetshire, does not exceed 10 feet at Wootton-under-Edge, but becomes greatly developed at Cleevecloud near Cheltenham, where it is 300 feet thick, and at Bredon Hill, further north, nearly 400 feet.

Leicestershire.—Its maximum, in Leicestershire, is 300 feet, and in Northamptonshire it varies from 130 to 200 feet. Towards the Humber in Lincolnshire its thickness diminishes to about 60 feet.

Yorkshire.—The Upper Lias or Alum Shale of Yorkshire attains a remarkable development, and possesses a large fauna in fine preservation; it varies in thickness from 50 to nearly 200 feet. The Jet beds occur in the lower portion above the "*hard shales.*" This upper division is divided into three zones characterised by special ammonites, as in the Lower and Middle Lias. They are in upward succession—

1. The Zone of *Ammonites (Harpoceras) serpentinus.*
2. „ *Ammonites (Stephanoceras) communis.*
3. „ *Ammonites (Lytoceras) Jurensis.*

These horizons are succeeded by the "Dogger" or base of the Inferior Oolite, which is finely seen at the Peak and in the sections above the Upper Lias between Boulby and Easington, &c. &c. Nowhere in Britain is the Upper Lias so finely developed as along the Yorkshire Coast, *between the Peak south of Whitby and Saltburn south of Red-*

[1] *Vide* Rutland memoir (*loc. cit.*) for complete analysis of the Upper Lias of that county by Prof. Judd.

car.[1] Lithologically, the Yorkshire Upper Lias differs from that of all other localities, and certainly contains the richest known fauna either in Britain or the Continent.

(1.) Zone of *Ammonites* (*Stephanoceras*) *Annulatus.*

Position.—Messrs Tate and Blake [2] place the beds containing this ammonite at the close of the Middle Lias, or above the *Spinatus series.* The group of shales comprising this Zone was termed by Young and Bird [3] in 1882 the "*Hard and compact alum shale.*"

Petrological Character.—The rock is a hard micaceous sandy shale. "Rows of small ferrugineo-argillaceous limestone balls occur at irregular intervals throughout the Zone. They are extremely hard, and dark iron-grey in colour, and *mostly* unfossiliferous. About the middle of the Zone, however, nearly every nodule contains specimens of *Ammonites annulatus* or the alveolus of a Belemnite." This Zone is remarkably constant in mineral or petrological character, and is persistent throughout the Cleveland area above the Ironstone. Its average thickness is 30 feet.[4]

Distribution.—The Zone of *Am.* (*Stephanoceras*) *annulatus*, where exposed, conforms to that of *Spinatus* on which it rests. At the "Peak" it occurs on the sea-shore, is conspicuous in the Hawsker cliffs, and descends to the sea-shore at Hawsker bottom, covering the argillaceous iron bands of the *Spinatus* Zone.

North of Whitby, it is a marked feature in the cliffs and fore-shore, especially between Port Mulgrave and Brackenbury Wyke. It is most conspicuous at Old Nab, and above Staithes, along the front or face of Boulby cliffs its band of 30 feet, above the *Spinatus* Ironstones, cannot be mistaken.

In the northern escarpment of Upleatham, Eston, and Normanby it is characteristic, and is typically developed in Glaisdale between Egton and Grosmont, &c.; 45 species have been collected from this Zone.[5] The type ammonite (*A. annulatus*) is confined to these shales, and is extremely abundant, and therefore stratigraphically important. The mass of the fossils are located towards the base of the shales.

The list of species given by the authors of "The Yorkshire Lias" contains more Middle than Upper Lias forms; hence from the facies of the Fauna they include the grey shales with the Middle Lias.

[1] See Phillips' "Geol. of Yorkshire;" Tate and Blake, "Yorkshire Lias."
[2] "Yorkshire Lias," p. 168.
[3] Geol. Survey of the Yorkshire coast, p. 142, 4to. 1822.
[4] At Hawsker, 36 feet; Staithes, 40 feet; Rockcliff, 31 feet; Hob Hill, 31 feet; Eston Nab, 33 feet; Cod Hill, Guisborough, 30 feet; Glaisdale, 25 feet. The nodules with *Am. annulatus* abound along the fore-shore at Sandsend, Port Mulgrave, and Whitby.
[5] The great abundance of *Am. annulatus* in these hard grey shales was first noticed by Louis Hunton—Trans. Geol. Soc. 2nd. ser., vol. v. p. 215. (Section of the Upper Lias and Marlstone of Yorkshire, showing limited vertical range of the species of Ammonites and other Testacea, with their value as geological tests.)

Fauna.—The Ammonites are *Am.* (*Stephanoceras*) *annulatus, A. concavus, A. Lytoceras cornucopiæ, A. semisulcatus;* and the seven species of *Belemnites, B. cylindricus, B. latisulcatus, B. breviformis, B. pollex, B. validus, B. striolatus, B. scabrosus*—9 species of Gasteropoda and 19 Lamellibranchs, with *Rhynchonella jurensis* and *Extracrinus briareus?* represent the fauna of these grey shales.

(2) *The Zone of Ammonites* (*Harpoceras*) *Serpentinus.*

Distribution.—This is one of the most widely distributed Upper Lias ammonites, both in Britain and on the Continent. Few sections occur in which the Zone of *serpentinus* is not present. Wherever the base of the Upper Lias is exposed—from Dorsetshire to Yorkshire—this Zone appears constant and continuous.[1] In the escarpments of the Cotteswold Hills the *serpentinus*, clays, and marls attain a thickness in some places of 80 feet, interposed between the *Spinatus* shales and the beds with *Harpoceras bifrons.*

On the summits of Bredon, Alderton, Gretton, and Churchdown Hills (all outliers of the Cotteswold), are fine sections of the *Serpentinus* beds, which are capable of being subdivided into 5 sections (*vide* Wright, Trans. Pal. Soc., p. 117, for details).

1*st.* The first *Division*, or that immediately resting upon the marls of the *Spinatus stage*, consists of blue and yellow clays, with *Harpoceras falciferum, Belemnites acuarius*, and *Rhynchonella pygmæa.*

2*d.* The thin marly *Leptæna-bed* containing (as near Ilminster) many species of minute Brachiopoda, belonging to the genera *Leptæna, Spiriferina, Rhynchonella, Terebratula, Thecidium*, &c.[2] None of the species appeared earlier in the *Spinatus* stage.

3*d.* Mottled laminated clays, many feet thick, rich in small Gasteropoda—*Cerithia, Rostellariæ, Trochus*, &c.; many bivalves, *Leda, Posidonomya, Arca*, with *Acrosalenia crinifera* and *Pseudodiadema Moorei.*

4*th.* A thin band of nodular argillaceous limestone, under a foot in thickness, termed the "Fish-bed," with *Pachycormus latirostris, Leptolepis concentricus*, and *Tetragonolipis discus.* At Dumbleton and Gretton the wings and elytra of insects occur in nodules—amongst them those of *Libellula Brodiei*—one of the Neuroptera.

5*th.* Brown fossiliferous clays, their thickness being governed locally by the amount of denudation the upper beds have undergone.

The summit of the outlying mass of Churchdown Hill contains the same series. They have been carefully described by the Rev. F. Smithe.[3] This Zone of *Am.* (*Harpoceras*) *serpentinus*, in Gloucestershire, has yielded 21 genera and 31 species.

The Upper Lias of Ilminster (Somerset) has become classic through the labours of Charles Moore, the results of which are now displayed

[1] Dr. Wright, through careful study of the Palæontology of the Upper Lias, has distinguished therein 4 faunas, having many well-defined species characteristic of each. These zonal faunas are those of the Ammonites, *A. serpentinus, A. bifrons, A. Jurensis*, and *A. opalinus.*

[2] This thin Zone occurs under the same conditions, and occupies the same stratigraphical position at Curcy la Caine, and other localities in Normandy, as it does in Somersetshire and Gloucestershire, yielding also the same species. Mr. C. Moore obtained 150 species from these Leptæna marls (not 6 inches thick) at Ilminster. (See C. Moore, Middle and Upper Lias of the South-West of England. Proc. of the Somerset Archæol. Soc., vol. xiii., p. 16, 1865–6).

[3] The Geology of Churchdown Hill (Cotteswold Club, 1861.)

in the Museum of the Philosophical Society at Bath. No less than 10 subdivisions with a fauna of nearly 200 species may be determined in the *Serpentinus* Zone at Ilminster.

Yorkshire.—"The Jet Rock Series, or the Zone of Harpoceras (Ammonites) Serpentinum."— Messrs. Tate and Blake give this designation to the series of beds which occupy the lower portion of the Upper Lias, lying above the *Annulatus* shales, and beneath the rocks containing *Ammonites communis* and *Am. bifrons*. They are commonly called the "Jet Rocks." Strictly speaking, this is misleading (on palæontological grounds) on account of our being obliged to include beds that do not yield jet, which is quite a local and accidental circumstance or condition.[1] The upper beds of this series gradually pass into the overlying *Communis* shales.

The succession of these rocks is best observed and understood on the coast. Immediately south of Whitby, near Saltwick Nab, about 50 feet of this Zone are exposed, with numerous characteristic fossils; the upper 10 feet of blue shales yield *Ammonites* (*Harpoceras*) *elegans*, *A.* (*Harpoceras*) *serpentinus*, *A.* (*Phyllocerus*) *heterophyllus*, *A. delicatus*, *Belemnites tubularis*, *B. dorsalis*, and *Inoceramus dubius*. Below, in the large lenticular Doggers, sulphurous or "Cheese" Doggers, *Inoceramus dubius* occurs in great abundance.[2] Hard sub-bituminous shales 16 feet thick succeed, containing *Posidonomya Bronnii*. The remarkable fish *Gyrosteus mirabilis* occurs in the "*Animal*" *Dogger*, or indurated band 1 foot thick; the lower, 20 feet, being the hard blue bituminous shale ("Jet Rock") with Fish, Reptilia, &c. The most abundant and characteristic shell of this series is *Inoceramus dubius*, no exposure occurs without it.[3]

Range of the Jet Rock, or Serpentinus Series.—A little south of the Peak Fault, at "Blea Wyke," the Jet Rock rises to the sea level and exposes the "*Cheese*" *Doggers*, 4 or 5 feet in diameter, elevated on cones of shale. They are again seen on the shore at Saltwick, and further north between Sandsend and Kettleness; north of Runswick they lie on the shore and determine the place of the Zone; on to Staithes they occur in the cliffs. In Boubly Cliffs the Jet Rock forms a well-marked band to the western extremity of Lofthouse Alum Works.[4] Between the base of the Dogger or Inferior Oolite and the *Annulatus Zone* (at Saltwick), the Upper Lias is 180 feet thick, and in this thickness no less than six species of Belemnites hold *special horizons* in the cliffs. *Bel. Voltzii* and *Am. bifrons* occur in the cement nodules immediately below the "Dogger;" *B. vulgaris*

[1] It is through the search for jet that this Zone inland has numerous exposures around the northern and north-western escarpments.

[2] Not the *Inoceramus dubius* of Phillips.

[3] The most characteristic Fish is *Lepidotus semi-serratus*; all the species are peculiar to these beds, and belong to the genera *Pachycormus* (7 species), *Ptycholepis*, *Leptolepis*, *Gyrosteus*, *Aspidorhynchus*, and *Æchmodus*. The Enaliosauria—*Plesiosaurus* and *Ichthyosaurus*, *I. tenuirostris* and *Plesio. longirostris*, and *P. propinquus*, with the Crocodilian Steneosaurus (one of the Mesosuchia).

[4] See the "Yorkshire Lias," pp. 175–177, where the most complete geographical distribution is given.

and *Ammonites ovatus* 80 feet lower down in the Ball bed; *B. subtenuis* in the "Red bed;" *B. tubularis* and *B. lævis* in the beds containing "spheroidal balls;" and *B. tripartitus* in the Jet bed.[1] Thirty genera and sixty-six species occur in the Zone of *Am. serpentinus* in Yorkshire.

(3.) *Zone of Ammonites (Harpoceras) Bifrons.*

Under the title "*Communis*" or "*Alum shale*," the authors of the "Yorkshire Lias" include the well-known *Am. bifrons* series. The name "Alum shale" is highly appropriate for its northern development, it being from these shales that the manufacture of alum was for many years carried on. There is no lack of exposures along the sea-shore, or in many of the inland valleys, where it supports the overlying sandstones and shales of the Inferior Oolite, or the Jurensis Sandstones, where they may have been developed. But although it is largely exhibited in the interior of the county, it is only on the coast that this Zone can be satisfactorily examined: The upper portion contains lines of argillaceous nodules used for the manufacture of hydraulic cement. Below these is the main supply of Alum shale, associated with which is the typical shell "*Leda ovum.*" Close to Whitby this Zone measures 107 feet in thickness.

Exposures or Distribution of Am. Communis and the Alum Shale.—This Zone is first seen on shore between Blea Wyke and the Peak, its base being about 20 feet up the cliff south of the Fault. It ranges along the cliffs from Hawsker Bottoms (*Sawdon's* Path) to Whitby. North of Whitby it is seen at Sandsend, and onwards to Kettleness; it forms the "Shale Gorge" of the Boulby and Easington Becks, and on to the high ground occupied by the Boulby and Lofthouse Alum-Works; from the old alum-works at Skelton it can be traced into Eston Nab, and Slape Wath near Guisborough, and thence to Hutton and Roseberry Topping, and along the extended line of escarpments to the west.

Inliers of the Communis Beds.—In every valley both in the *north* and *south* central groups, or in the Esk valley, and the Seven, Dove, and Bilsdale vales, this Zone skirts the sides of the escarpments constantly exposed,[2] and is below the Oolite or Doggers.

Palæontology.—It is from this Zone in the old alum-works near Whitby that the large species of Enaliosauria and Crocodilia were all obtained—both *Ichthyosauria*[3] and *Plesiosauria*,[4] and the Amphicælian crocodile *Teleosaurus*. This Zone is richer in Reptilia than that of *Ammo. Serpentinus*, or the Jet Rock beds. The huge *Plesio-*

[1] Professor Phillips was long engaged in determining the several horizons in the Lias through the distribution of the Belemnites as well as the Ammonites. The above species in the vertical space of 180 feet are Zonal, through the Upper Lias.

[2] Consult "The Yorkshire Lias," pp. 185–187, for all the chief inlying localities and exposures (12) of the Alum shale series.

[3] Ichthyopterygia (Owen). [4] Sauropterygia (Owen).

sauri come from these shales at Whitby, Kettleness, and Boulby; and the Whitby shale is the home of *Teleosaurus Chapmanni*.

In the south of England the Reptilia chiefly occur at the base of the Lower Lias. In Yorkshire they occur only in the Upper Lias, none being known from the Lower and Middle Lias north of the Humber.[1] The Yorkshire species differ congenerically from those of the Midland and Southern Lias. Three of the four Upper Lias species of Ichthyosauri at Whitby—viz., *I. acutirostris*, *I. intermedius*, *I. platyodon?*—occur in the *Lower Lias* of the south, but not in the southern Upper Lias—the great *I. crassimanus* (in the York Museum) being a northern Upper Lias form only. Four of the five species of Plesiosauri are Yorkshire only—viz., *P. brachycephalus*, *P. cramptoni*, *P. homalospondylus*, and *P. Zetlandicus*—and all from the Upper Lias.[2] The Cephalopoda, through both the *Ammonitidæ*, and *Belemnitidæ* abound in the *Bifrons* and *Communis* Zones; 15 species of the former and 4 of the latter profusely lie in the shales associated with *Nautilus astacoides* and *N. jurensis*; these and *Leda ovum* dominate all others. The specially characteristic fossils are the Reptilia mentioned above, with *Ammo.* (*Phylloceras*) *heterophyllus*, *Am.* (*Harpoceras*) *elegans*, and *H. Levesoni*; *Gresslya rotundata*, *Arcomya elegans*, *Hinnites papyraceus*, *Thracia glabra*, *Inoceramus cinctus*, *Lingula longoviciensis*, and *Eryon Hartmanni*.

Gloucestershire.—Frocester Hill, Crickley Hill, and Stinchcombe Hill, are localities where the beds containing this typical Ammonite and its associate fauna occur.

Near Bloxham in Oxfordshire, on the Banbury and Cheltenham Railway, a numerous Upper Lias fauna, comprising no less than 181 species, has been described by Mr. Beesley.[3]

Lincolnshire.—In the north-west portion of Lincolnshire, in the Santon Railway cutting, this horizon has been investigated by the Rev. J. E. Cross, who has collected the typical Ammonites *Harpoceras serpentinum*, *Stephanoceras commune*, *Lytoceras cornucopiæ*, and *Amaltheus spinatus*.[4]

Foreign Palæontological Correlations.—The Upper Lias in S.W. Germany has been divided by Quenstedt[5] into "*Posidonienschiefer*" and "*Jurensis-Mergel*," the former corresponding to the *Serpentinum* and *Bifrons Zones*, and the latter to the Zones of *Jurense* and *Opalinum* of Dr. Wright.[6] The *Posidonienschiefer*, &c., are characterised by the presence of many genera of fish.[7] The *Jurensis-Mergel* is char-

[1] Barrow-on-Soar may be said to be the last northern exposure of Lower Lias, wherein have been obtained the Enaliosauria, no less than 4 species and numerous skeletons having been obtained through working the cement beds.

[2] Besides the above, portions of five other species occur, *P. cœlospondylus*, *P. dubius*, *P. longirostris*, *P. macropterus*, *P. propinquus*.

[3] "Geology of the Banbury and Cheltenham Railway," Proc. Geol. Association, vol. v., 1877. The Ammonites are *Am.* (*Harpoceras*) *bifrons*, *H. latescens*, *H. subplanatum*, *H. Levisoni*; *Am.* (*Stephanoceras*) *commune*, *S. crassum*, *S. Holandrei*, *A. fonticulum*, and *S. gracile*; *Am.* (*Lytoceras*) *cornucopiæ*, *Am.* (*Phylloceras*) *heterophyllum*, *P. subcarinatum*, *Nautilus astacoides*, and *N. Jourdani*. . . . For list of species see Pal. Soc. Mono. Lias Ammo., by Dr. Wright—Zone of *Am.* (*Harpoceras*) *bifrons*, pp. 128–29. 1878.

[4] Q. Jour. Geol. Soc., vol. xxi. 1875.

[5] "Flözgebirge Würtembergs," p. 539, 1843.

[6] Palæontographical Soc., Mono. on the Lias Ammonites, Dr. Wright, pp. 137–150.

[7] *Ptycholepis Bollensis*, *Eugnathus Tetragonolepis*, *Pholidotus semicinctus*, *Lepidotus Elveonis*, *L. semiserratus*, *L. dentatus*, *Semionotus leptocephalus*, *Aspidorhyn-*

acterised by the *absence* of fish-remains, and the appearance of a new suite of Cephalopods, as *Lytoceras jurense*, *Harpoceras insigne*, *H. variabile*, *H. striatulum*, *H. radians*, *H. Aalense*, and many others.[1]

Quenstedt[2] carefully described the Palæontology of the Lias "Epsilon" at Boll, in which he finds *Teleosaurus Chapmanni*, *T. Bollensis*, *Plesiosaurus suevicus*, *Ichthyosaurus longirostris*, and 3 other species, and adds the following rich list of Vertebrata and Cephalopoda:—*Hybodus pyramidalis*, *H. reticulatus*, *Acrodus nobilis*, *Lepidotus Elvensis*, *Dapedius cælatus*, *D. punctatus*, *D. Leachei*, and *D. pholidotus*; *Tetragonalepis semicinctus* and *T. cinctus*, *Ptycholepis Bollensis*, *Pholidophorus germanicus*, *Belonostomus acutus*, *Pachycormus curtus*, *P. macropterus*, *P. Bollensis*, *Thrissops micropodius*, *Leptolepis Bronnii*, *Lycodus gigas* and *Pachylepis sp.* In addition to the foregoing he gives a remarkable assemblage of Cephalopoda, comprising 4 genera and 22 species; *Loliginites* 5 species, *Onychoteuthis conocauda*, *Onychites* 2 species, *Belemnites* 4 species, all British, and Ammonites 10 species, 8 of which are also British forms.[3] Lamellibranchiata 11 genera and 15 species, 6 of which belong to the Upper Lias of England. Of the 4 Echinodermata named, 2 species, *Acrosalenia crinifera* (*minuta*), *Pentacrinus Quenstedti*, are also British species.

France.—These same series, under the name *Posidonomya* beds, are considerably developed in many departments. M. Terquem has described them in the Moselle,[4] where they consist of 3 groups.

1. (*a*) Marnes bitumineuses.
2. (*b*) Calcaire noduleux.
3. (*c*) Calcaire grèseux.

In the Dept. of the Yonne M. Cotteau[5] terms this series "*Lias supérieur, masse argilobitumineuse.*" Placing them under his *First stage*, Upper Lias—*Posidonomya Bronni*, *Harpoceras bifrons*, *H. falciferi* and *Lytoceras cornucopia* are there also the characteristic species.

A similar condition of the Posidonomya beds prevails at Flavigny, in the Côte d'Or, where M. Collenot describes 4 Zones.

Zone 1, with *Harpoceras serpentinum*, *S. Holandrei*, *Phylloceras heterophyllum*, and *H. bifrons*, all British species.

Zone 2, with *Harpoceras complanatum.*

Zone 3, with *Pecten pumilus and Turbo subduplicatus.*

Zone 4, with *Stephanoceras mucronatum.*[6]

In the Department of the Isère in the S.E. of France, at Verpillière and St. Quentin, the *Posidonomya* beds are rich in fossils; of the 9

chus, *Pachycormus*, *Thrissops*, and *Leptolepis*; and Reptilia, as *Ichthyosaurus*, *Plesiosaurus*, and *Teleosaurus*. CEPHALOPODA—*Harpoceras serpentinum*, *H. bifrons*, *H. Lythensis*, *Phylloceras heterophyllum*, *Lytoceras cornucopiæ*, and *Belemnites acuarius*; PELECYPODA, as *Inoceramus dubius*, *Posidonia Bronni*, *Monotis substriatus*, and *Leda ovum*; BRACHIOPODA, as *Discina reflexa*, &c.

[1] These species of Ammonites and those above mentioned are all British.

[2] Der Jura, p. 210.

[3] No less than 12 genera and 12 species of the Fish above named from S.W. Germany also occur in our *Ammonites bifrons* Zone in Yorkshire and Somersetshire; and 12 of the 22 cephalopoda.

[4] Palæontologie du Dépt. de la Moselle, Ext. de Statist. de la Moselle, p. 20. 1855.

[5] Études sur les Échinides. Foss. du Départ. de l'Yonne, p. 32.

[6] Description Géologique de l'Auxois, 1873.

species of Ammonites that occur, 8 are British, and also *Belemnites acuarius*.

In the Department of Averyon both the *Posidonomya* and *Am. jurensis* beds are in natural superposition, the Upper Lias being well developed. Dr. Reynès[1] there divides the Upper Lias into 4 parts.

1. The Zone of *Harpoceras serpentinum*.
2. „ „ *bifrons*.
3. „ *Lytoceras jurense*.
3. „ *Harpoceras opalinum*.

He shows the independent nature of the above Zones, and demonstrates the little affinity that exists between them as regards the admixture of species.[2]

Prof. Deslongchamps in his "Mémoire sur la couche à Leptæna du Lias: Études sur les Étages jurassiques Infér. de la Normandie (1864)," correlates the Upper Lias beds of Normandy with those of Gloucestershire and Somersetshire. The Zone of *Am. Bifrons* is well developed at Courcy and May, near Caen in Calvados. The Leptæna bed at Courcy, as in Somerset and Gloucester, yields a singular and rich assemblage of organic remains, and affords a remarkable instance of the continuity and distribution over an extended area of identical forms of life—the same beds in Britain being discovered and worked out by Mr. C. Moore in Somersetshire, and the Gloucestershire species at Churchdown Hill by the Rev. F. Smithe (*loc. cit.*)

Belgium.—Drs. Chapuis and Dewalque[3] have described these same Zones as "Marne de Grand-cour," where at Aubange they have yielded Reptilia, Fishes, and the following characteristic Ammonites which occur in the Lower Zone, 7 being British :—*Harpoceras serpentinum, Harp. Lythense, H. complanatum, Pylloceras heterophyllum, Lytoceras cornucopiæ, Stephanoceras Raquinianum, S. Holandrei, S. mucronatum*, and *S. Braunianum*. From this Zone they have also determined *Harpoceras radians, H. Levesquei, H. variabile*, and *H. comense*.

(4.) *The Zone of Ammonites (Lytoceras) Jurensis.*

This is the uppermost Zone of the Lias, and immediately underlies the calcareous beds of the Inferior Oolite, the lower beds of which differ essentially in their petrological character from any in the great Liassic series below, which we have endeavoured to trace. Physically and palæontologically no change can be more complete, for only 33 *genera* and 45 *species*, out of 281 genera and 1830 Liassic species, pass up from the Lias to the Inferior Oolite. Throughout the tortuous line of demarcation or separation between the sands or clays of the Upper Lias and the Oolite along the Cotteswolds range, the change is sharp and constant.

This Zone is well developed in the counties of Dorset, Somerset, Gloucester, Northampton, and Lincoln, across the Humber into York-

[1] Essai de Géologie et de Palæontologie Aveyronnaises. 1868.

[2] See the analysis of Dr. Reynès' researches in the Upper Lias by Dr. Wright in the Pal. Soc. Mono. On the Lias Ammonites (Zone of *Harpoceras bifrons*), p. 134-36. 1879.

[3] "Lias de la province de Luxembourg." 1857.

shire, but differing petrologically in the latter county, especially so after leaving the latitude of Market Weighton, where the Inferior Oolite series assume the arenaceous, shelly, and estuarine type.

The *Jurensis* Zone is essentially a passage series; the peculiar species are in a minority, and the Ammonites show this. The junction of the Inferior Oolite with the beds comprising the *Jurensis* series in Yorkshire is only to be seen at the Peak; here there are four thick beds of sandy micaceous shale, separated by nodular fossiliferous bands. Many species are common to the Dogger or Inferior Oolite above; they are:—*Discina reflexa*, *Monotis substriatus*, *Pecten disciformis*, *Venus tenuis*, and *Gresslya abducta*. About thirty species complete the Fauna of the *Jurensis* series at the Peak.

Gloucestershire.—The *Jurensis* beds are advantageously shown at Frocester Hill, near Stonehouse, and also in the Nailsworth and Brimbscombe Valleys in Gloucestershire. Organic remains are rare in the *Jurensis* Sands, few localities yielding any.

Somersetshire.—The *Jurensis* Zone occurs in several sections south of the Mendip Hills, resting upon the clays of the Upper Lias. In places these Sands attain a thickness of 100 feet, as at Yeovil and Bridport Harbour. Near Bath they are 40 feet thick; also at Midford,[1] hence the origin of the name "Midford Sands," given by Professor Phillips.[2]

Dorsetshire.—Near the summit of Chideock Hill, between Bridport and Charmouth, and also at Burton Bradstock, and on the east side of Bridport Harbour, the Zone is grandly shown in the cliffs, the Sands there being over 150 feet in thickness; few fossils occur in them.

Near Yeovil station, Bradford Abbas, and near Sherborne, they occupy a considerable area; at Sherborne these *Jurensis* Sands are 140 feet thick. Many of the species of the Upper Lias continued to live on through the Sands into the shelly bed (Cephalopoda bed) above. This was especially the case with certain species of Ammonites, in such well-known forms as *Am. bifrons*, *A. opalinus*, *A. striatulus*, *A. concavus*, *Belemnites compressus*, *B. irregularis*, and *B. tripartitus*. On the other hand, many Conchifera which occur with the above Cephalopoda have Oolitic and not Liassic affinity, *Hinnites objectus*, *Trigonia striata*, *Modiola Sowerbyii*, and *Pholadomya fidicula* not occurring below the middle of the Sands.

The Cephalopoda bed, with its rich assemblage of Ammonites and Belemnites,[3] is everywhere developed along the western front or escarpment of the Cotteswold Hills, extending from Cleeve Cloud to Wootton-under-Edge, again appearing between Yeovil and Sherborne

[1] Near the old residence of William Smith.

[2] "Geol. of Oxford and Valley of the Thames," p. 118.

[3] *Ammo. opalinus*, *A. bifrons*, *A. insignis*, *A. kircinus*, *A. jurensis*, *A. striatulus*, *A. Thouarsensis*, *A. radians*, *A. Moorei*, *A. discoides*, *A. concavus*, *A. variabilis*, *Belemnites compressus*, *B. tripartitus*, *B. irregularis*, *B. nodotianus*, *B. breviformis*, and *Nautilus inornatus*, with thirty-four genera and thirty-eight species of Conchifera.

in Somersetshire and on the Dorsetshire coast near Bridport; it is also recognised in France.

The cliffs at Bridport Harbour are capped by the three Zones of *Am. Murchisonæ*, *A. Humphresianus*, and *A. Parkinsoni;* here all three united are not more than 10 feet thick, the whole thickness in the Cotteswold series of the Cheltenham area having thinned away on their strike from nearly 400 feet to 10 feet, yet these three life Zones are still intact, rich in their respective species, and in fine preservation.

Numerically, the Fauna of the Zone of *Ammo.* (*Lytoceras*) *Jurensis* is 39 genera and 70 species; the Ammonites alone[1] numbering 13, and the Pelecypoda 38 species.

None of the Cephalopoda pass up into the Inferior Oolite, but 18 of the 48 other species of Mollusca are common to the Upper Lias or *Jurensis* Zone and succeeding Inferior Oolite.

Foreign Correlations.—Professor Quenstedt first pointed out that the *Jurensis-mergel* was the uppermost member of the "Schwarzer Jura."[2]

"In North Germany the *Jurensis* Zone has been described by von Strömbeck, Ewald, and Credner, as found in the Helmstedt, Halberstadt, and Harzburg Jura; and as in Würtemberg and Britain, yielding the same Ammonites, &c., viz., *Lytoceras jurense*, *Harpoceras insigne*, *Lyt. hircinum*, *Harp. variabile*, *Harp. radians*, and *Belemnites irregularis*."

(5) *Zone of Ammonites* (*Harpoceras*) *Opalinus.*

The fossils occurring in this Zone were formerly included with the Cephalopoda bed at Frocester Hill. Chideock Hill and Burton Bradstock, near Bridport in Dorsetshire, yield this Ammonite in a thin bed *immediately* below the Inferior Oolite in the passage-bed between the two formations. The thin hard ferruginous *opalinus* marl at Haresfield is the boundary line between the Lias and the Inferior Oolite. Probably the well-known thin friable shale immediately below the Dogger, and above the dark-yellow sandstone at Blea Wyke-under-the-Peak, near Robin Hood's Bay, and containing *Terebratula trilineata*, *Trigonia Ramsayi*, *Bel. compressus*, and *Rhynchonella cynocephala*, may represent the Zone of *Harpoceras opalinum*.

"Dr. Oppel[3] found the *Opalinum* beds in Würtemberg in the Swabian Alps, and near Gmünd, Boll, Metzingen, &c., in Bavaria, near Altdorf and Neumarkt, and in Baden near Kander."

In North Germany Rolle recognised the stratum near Hildesheim and Goslar.[4]

[1] In the new nomenclature, Lytoceras $\frac{1}{3}$; Harpoceras $\frac{1}{13}$.

[2] Flözgebirge Würtembergs, pp. 267 and 539. 1843.

[3] "Juraformation," p. 308.

[4] "Versuch einer Vergl. des Norddeutschen Lias mit dem Schwabischen." 1883.

Strömbeck at Schoppensted,[1] Ewald at Hoym in Saxony,[2] Seebach near Wentzen, at the south margin of Hills,[3] have at each locality obtained evidence of this Zone (Wright, *loc. cit.*, p. 148–9).

France.—Dumortier[4] has found this Zone in the Rhone Valley in many localities, and especially notices Verpillière and Isère, naming therefrom 18 species of Cephalopoda, 9 of which are British.[5]

In France, *Harp. opalinum* and *Lytoceras torulosum* are the leading fossils of this Zone. 17 localities have yielded them.

[1] "Thon mit Am. Opalinus," Zeitschr. d. Deut. Geol. Gesell., vol. v. p. 102.
[2] "Schicht. des *Am. opalinus*," Sitzber. d. Berlin. Akad., p. 350.
[3] "Der Hannoversche Jura," p. 3.
[4] "Dépôts jurassiques du Bassin du Rhône," vol. iv. p. 237.
[5] *Bel. exilis, B. tricanaliculatus, B. Dorsetensis, Nautilus lineatus, Harp. opalinum, H. Aolense, L. kircinum*, and *Lyto. torulosum*.

TABLE LIX.—*Stratigraphical Distribution of the Ammonitidæ through the Upper Lias of the British Islands.*[1]

Families, Genera, and Species.	Serpentinum.	Bifrons.	Jurense.	Opalinum.
Family LYTOCERATIDÆ.				
Genus LYTOCERAS.				
Lytoceras cornucopiæ, Y. and B.		×		
„ *hircinum*, Schub.				
„ *Jurense*, Zeiten.			×	
„ *torulosum*, Schub.			×	
			×	
Genus PHYLLOCERAS.				
Phylloceras heterophyllum, Sow.		×		
„ *subcarinatum*, Y. and B.		×		
Family AEGOCERATIDÆ.				
Genus HARPOCERAS.				
Harpoceras serpentinum, Rein.	×			
„ *elegans*, Sow.	×			
„ *falciferum*, Sow.	×			
„ *exaratum*, Y. and B.	×			
„ *Lythense*, Y. and B.		×		
„ *latescens*, Simp.		×		
„ *ovatum*, Y. and B.		×		
„ *subplanatum*, Oppel		×		
„ *primordiale*, Scloth.		×		
„ *bifrons*, Brug. = *Walcotti*, Sow.		×		
„ *Levisoni*, Simp.		×		
„ *insigne*, Schub.			×	
„ *comense*, Von Buch.			×	
„ *discoides*, Zeiten.			×	
„ *Thouarcense*, D'Orb.			×	
„ *striatulum*, Sow.			×	
„ *radians*, Rein.			×	
„ *Raquenianum*, D'Orb.			×	
„ *undulatum*, Stahl.			×	
„ *Variabile*, D'Orb. = var *Beanii*			×	
„ *Aalense*, Zeiten.			×	×
„ *Opalinum*, Rein.				×
„ *Moorei*, Lycett.				×
„ *subinsigne*, Oppel				
Genus STEPHANOCERAS.				
Stephanoceras annulatum, Sow.	×			
„ *crassum*, Y. and B.	×	×		
„ *Holandrei*, D'Orb.	×	×		
„ *commune*, Sow.		×		
„ *fibulatum*, Sow.		×		
„ *subarmatum*, Y. and B.		×		
	7	15	13	3

[1] Palæontographical Soc., vol. xxxiii. 1879.

CHAPTER XXXVI.

LOWER JURASSIC ROCKS: INFERIOR OOLITE.

THE Lower Jurassic rocks of Britain comprise the following five subdivisions:—

1. The Inferior Oolite, divisible into four life zones.[1]
2. „ Fuller's Earth.
3. „ Great Oolite with the Stonesfield slate at the base.
4. „ Forest marble and Bradford clay.
5. „ Cornbrash.

Inferior Oolite.

Physical Characters and Range.—The Inferior Oolite attains its maximum development in the Cotteswold Hills, and in the neighbourhood of Cheltenham, where at Leckhampton and Cleeve Hills it reaches a thickness of nearly 300 feet, and is composed of calcareous, fossiliferous freestones and grits. Palæontologically, the Inferior Oolite is readily subdivided, as in the Lias, into three if not four life-zones, based upon the vertical or time distribution of the Ammonitidæ, and many associated forms of almost equal importance, especially the *Echinodermata* and *Actinozoa*. The component strata of the Inferior Oolite are subject to great variations in thickness and lithological characters, both to the east and south, on their dip and line of strike.

The thick marine beds of the Cotteswolds of the Cheltenham, Gloucester, and Bath areas become reduced in thickness to a few feet, and alter in physical character also, as before stated. At Bridport harbour in Dorsetshire, the zonal division of the Inferior Oolite which at Cheltenham occupies strata over 300 feet thick, is there only 10 feet, each of the three zones, nevertheless, containing the same fauna, abundantly represented. To the east and north-east of the typical area, or towards Northamptonshire and Oxfordshire, they have undergone complete change both lithologically and in thickness, the limestones have passed into sandy ironstone-bearing strata only a few feet thick. The whole of the formations above named between the Lias clay (or Upper Lias sands where they occur) and the top of the Great Oolite have died out or thinned away into sands and beds of ironstone known as the Northampton Sands.[2] These lowest Oolitic or Jurassic strata have, through geographical changes, passed from the marine to estuarine conditions in their strike northwards into Rutland

[1] 1. The Zone of *Ammonites* (*Harpoceras*) *Murchisoniæ*. 2. The Zone of *Ammo.* (*Harpoceras*) *Sowerbyi*. 3. The Zone of *Ammo.* (*Stephanoceras*) *Humphresianus*. 4. The Zone of *Ammo.* (*Cosmoceras*) *Parkinsoni*.

[2] See paper by S. Sharp, Esq., "On the Oolites of Northamptonshire," Q. Jour. Geol. Soc., vol. xxvi., 1870, pt. 1; *ib.*, pt. 2, 1873.

and Lincolnshire, and finally Yorkshire, where they constitute the entire mass of the strata between the zone of *Ammonites Jurensis* and the Cornbrash; forming the series of estuarine sandstones, shales, and impure coals that everywhere spread over the East Riding. An abundant terrestrial flora, comprising 25 genera and 86 species, accompanies these estuarine beds in Yorkshire, the whole known Inferior Oolite flora numbering 41 genera and 130 species. The next and only large flora occurs in the Great Oolite, in which we know of 20 genera and 36 species. No plants are known either in the Forest marble, Bradford clay, Cornbrash, or Kelloway rock.

The complete section of the Inferior Oolite at Leckhampton Hill, near Cheltenham, exhibits the following subdivisions or distinctive beds:[1]—

The Upper Ragstones, including the *Gryphæa* and *Trigonia* beds, are constant and uniform in development throughout the Cheltenham area, and present a similar series of fossils wherever exposed, *being always* characterised by *Ammonites Parkinsoni*, *A. Martinsii*, *Trigonia costata*, *Perna rugosa*, *Clypeus sinuatus*, *Collyrites ringens*, *Holectypus depressus*, *H. hemisphærieus*, *Terebratula globata*, *T. sphæroidalis*, *Rhynchonella plicatella*, and *R. spinosa*.

No. 1. **The Trigonia Bed (Upper Trigonia Grit).**—Coarse brown ragstone, containing *Trigonia costata*, *T. decorata*, *Lima cardiiformis*, *Rhynchonella concinna*, *Ammonites Parkinsoni*, *Echinobrissus cluniculuris*, *Holectypus depressus*, and *Clypeus sinuatus*. The fauna comprises 28 genera and 42 species. The beds are about 7 feet thick.

No. 2. **The Gryphæa Beds (Gryphite Grit).**—Largely composed of *Gryphæa subloba* (*G. Buckmani*, Lyc.), *Myacites dilalata*, *Terebratula impressa*, *T. perovalis*, *Tancredia donaciformis*, *Gervillia tortussa*, *G. Hartmanni*, *Lutraria ovalis*, *Pholadomya fidicula*, *Cypricardia cordiformis*, *Modiola gibbosa*, *Pinna cuneata* and *Am. Parkinsoni*, &c. About 8 feet thick.

No. 3. **Lower Trigonia Grit.**—Light-coloured rubbly oolite, containing a large fauna (53 genera and 80 species). This Lower Trigonia Grit occurs at Leckhampton Hill, Rodborough Hill, and Ravensgate Hill, where the fauna is well preserved in a matrix of fine-grained sandy oolite with ferruginous grains of silicate of iron.

No. 4. Below the above "Upper Ragstones" occur *two series* of almost unfossiliferous beds, composed of coarse brown rubbly oolite, succeeded by the *upper flaggy bastard freestone*, which rests upon the oolite marl. Unitedly, these two are 50 feet thick.

No. 5. **The Oolite Marl or Fimbria Bed** in lithological structure resembles the Chalk Marl, being a cream-coloured mudstone. This marl is rich in fossils, and constitutes an important feature in the great section. The dominant shell is *Terebratula fimbria*, which occurs in thousands. Other characteristic forms abound, viz., *Lucina lyrata*, *Lima cardiiformis*, *L. lævisculu*, *Natica cincta* (*Leckhamp-*

[1] Consult the exhaustive paper by Dr. Wright "On the Palæontological and Stratigraphical relations of the so-called Sands of the Inferior Oolite," Q. Jour. Geol. Soc., vol. xii. p. 292–325.

tonensis), *Natica adducta, Mytilus pectinatus, Astarte elegans, Nerinæa, Chemnitzia*, and masses of the Coral, *Thamnastræa Mettensis*;—7 feet thick, succeeded by 100 feet of freestone or building stone. Poor in fossils.

6. **Freestone.**—Compact light-coloured oolitic limestone, about 100 feet in thickness, with few fossils, succeeded below by the singular and distinctive deposit termed the PEA GRIT, from the character or nature of its coarsely oolitic structure.

The Pea Grit is divisible into three sections:—

	Feet.
a. Coarse oolite, full of flattened concretions, cemented together by a calcareous matrix	12
b. Hard cream-coloured pisolitic rock, made up of flattened concretions	10
c. Coarse brown ferruginous rock, composed of large oolitic grains	20
	42

Numerically, the fauna of the Pea Grit comprises 59 genera and 114 species. The characteristic species in this rich fauna are—

CEPHALOPODA.—*Ammonites corrugatus, Nautilus truncatus*, and *Belemnites giganteus.*

GASTEROPODA.—*Pleurotomaria ornata, Patella rugosa, Cirrus nodosus, Natica adducta.*

PELECYPODA.—*Lima ovalis, Pecten lens, Hinnites abjectus, Mytilus pectinatus, Modiola Sowerbyia, Pinna cuneata, Myoconcha crassa, Avicula complicata, Ceromya Bajociana, Macrodon Hirsonensis, Myacites dilatata, Trigonia costata*, and *T. striata.*

BRACHIOPODA.— *Terebratula simplex, T. plicata, Rhynchonella decorata.*

ANNELIDA.—*Serpula socialis.*

ECHINODERMATA.—*Cidaris Fowleri, Acrosalenia Lycetti, Pseudodiadema depressum, Echinus germinans, Pygaster semisulcatus, Hybodypus* (*Galeropygus*) *agariciformis*, &c.

ACTINOZOA.—*Montlivaltia Delabechii, Thecosmilia gregaria, Thamnastræa Defranciana, Isastræa tenuistriata.*

Cephalopoda Bed.—Below the Pea Grit and ferruginous Oolite, or between these beds and the sands of the Upper Lias, occurs the so-called "*Cephalopoda bed*," which, although not exceeding 5 feet in thickness, is nevertheless a marked horizon or divisional line between the Upper Lias and the Inferior Oolite in the Cotteswold range. In reality, the Cephalopoda bed caps the summit of the Upper Lias; all the species of Ammonites, Nautili, and Belemnites (16 or 18) belong to the Upper Lias, none appearing above this definite band. Although none of the Cephalopoda pass to any higher horizon, there is community of species through the *Pelecypoda* with the Inferior Oolite, those species, amongst others common to the two horizons, being *Pholadomya fidicula, Gervillia Hartmanni, Modiola Sowerbyi, Astarte excavata, Hinnites abjectus, Perna rugosa*, and *Pecten demissus*, &c. &c. Probably 20 species unite the Upper Lias with the Inferior Oolite. The following species of Ammonites that occur in the Cephalopoda Bed of Gloucestershire and Dorsetshire equally characterise the same horizon in Germany, France, and Belgium, viz., *Ammonites opalinus, A. insignis, A. variabilis, A. discoides, A. striatulus, A radians,*

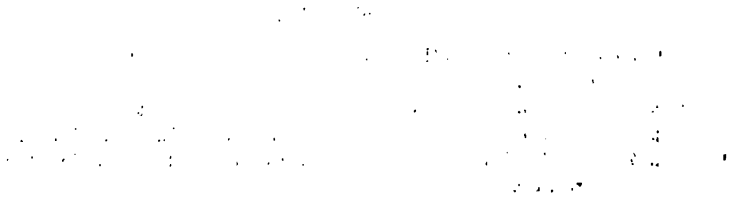


PLATE XX.

LOWER JURASSIC FOSSILS.

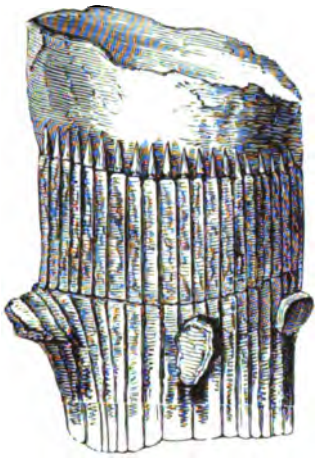
Inferior Oolite.

1. *Equisetites columnaris* (Brong.) Inferior Oolite shale. Gristhorpe, &c., Yorkshire.
2. *Pterophyllum.* Inferior Oolite shale. Yorkshire Coast.
3. *Pterophyllum comptum* (L. & H.) Inferior Oolite shale. Yorkshire.
4. *Tæniopteris vittata* (Brong.) Inferior Oolite shale. Whitby, Gristhorpe, &c.

PLATE XX.

LOWER JURASSIC FOSSILS.

Inferior Oolite.



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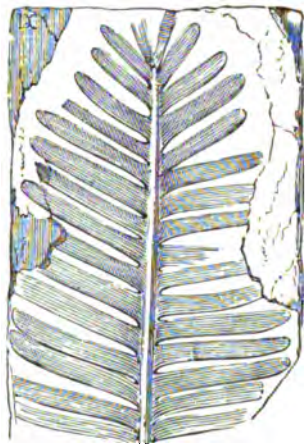

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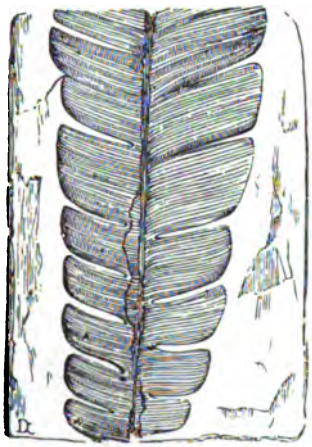

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4

A. Raquinianus, *A. hircinus*, and *A. Jurensis*, *Nautilus inornatus*, *Belemnites breviformis*, *B. compressus*, *B. nodotianus*, and *B. irregularis*, and, as with us, all are Upper Lias species. It is admitted that the Cephalopoda are the best indicators of geological time, the Pelecypoda and Gasteropoda having a much more extended stratigraphical or time range than other mollusca. Associated with the *Cephalopoda* are the *Echinodermata* and *Brachiopoda*, and together these three classes are of more value to the palæontologist than the Conchifera and Gasteropoda, arising from the fact of these species having a more limited range or distribution in time.[1]

To illustrate still more the importance of the ammonites in stratigraphical sequence, we trace the course of the Inferior Oolite of Gloucestershire and Dorsetshire; where best observed, it affords us clearer insight into the value of certain and associated species having restricted range in time.[2]

1. In Dorsetshire, as in Gloucestershire and the Midland Counties, the base of the Inferior Oolite commences with the zone of *Am.* (*Harpoceras*) *Murchisonæ*, which rests immediately upon the Upper Lias (or Inferior Oolite) sands; associated with *Harp. Murchisonæ* in Dorsetshire, at Wyke and Bradford Abbas are the following species:—*Rhynchonella subangulata*, *R. subtetraædra*, *Terebratula perovalis*, *T. Etheridgii*, and *T. simplex*. The same associated forms occur at Dundry near Bristol and the Cheltenham area.

2. Above, or succeeding, occurs the zone of *Am.* (*Harpoceras*) *Sowerbyi*, containing the following ammonites:—*H. adricum*, *H. Levesquei*, *H. fissilobatum* and *H. cornu* (Buck.), *Lytoceras confusum* (Buck.), and *L. amaltheus subspinatum* (Buck.); Wyke Quarry, Bradford Abbas, and Halfway House yield *Harp. Sowerbyi* and its above allies, and also *Astarte excavata*, *A. elegans*, and *Terebratula eudesii*.

3. The third horizon or zone of *Am.* (*Stephanoceras*) *Humphresianum* is an important one both at Dundry in Somersetshire and at Sherborne, Bridport, Lousehill and Wyke in Dorsetshire. A large and associated *Ammonite* fauna occurs with the type form; no less than 18 species range through and are confined to the zone of *S. Humphresianum*. They are *Am.* (*Harpoceras*) *cycloides*, *Am.* (*H.*) *Edouardianum*, *Am.* (*Cosmoceras*) *subfurcatum*, *Am.* (*C.*) *garantianum*, *Am.* (*Haploceras*) *oolithicum*, *Am.* (*Lytoceras*) *eudesianum*, *Am.* (*Stephanoceras*) *Blagdeni*, *Am.* (*S.*) *Brackenridgii*, *Am.* (*S.*) *linguiformæ*, *Am.* (*S.*)

[1] Dr. Wright, in his able paper, *loc. cit.* pp. 317–321, gives a stratigraphical table of distribution for these two horizons in England (the Upper Lias sands and the Inferior Oolite), and compares them with those of the same age in France, Belgium, and Germany. All research since has not altered the relation of one group to the other, or the distribution of the species with relation to Europe. The numerical value of the fauna catalogued in this extensive table is as follows:—Ammonites 28 species, Nautili 2, Belemnites 5, Gasteropoda $\frac{5}{70}$, Pelecypoda $\frac{2}{16}$, Brachiopoda $\frac{5}{70}$, Annelida $\frac{1}{8}$, Echinodermata $\frac{1}{13}$, Actinozoa $\frac{1}{13}$,—in all, 65 genera and 171 species, or $\frac{65}{171}$.

[2] See paper by Mr. S. S. Buckman on some of the species of Ammonites from the Inferior Oolite of Dorset, Q. Jour. Geol. Soc., vol. xxxvii., p. 588; also "The Cephalopoda Beds of Gloucester, Dorset, and Somerset," by Professor James Buckman, Q. Jour. Geol. Soc., vol xxxiii., 1877.

Deslongschampsii, *Am.* (*Sphæroceras*) *Brongniarti*, *Am.* (*S.*) *Gervillii*, *Am.* (*S.*) *Wrightii*, *Am.* (*Cosmoceras*) *Caumontii*, *Am.* (*Oppelia*) *subcostata*, *Ammo. Cadomensis*, and *Am.* (*Perisphinctes*) *Davidsoni*. Nearly every species named also occurs in the classic locality of Dundry near Bristol, and with them *Terebratula sphæroidalis*, *T. Buckmani*, and *Astarte obliqua*.[1]

4. The highest known and recognised zone in Gloucestershire, Somersetshire, or Dorsetshire is that characterised by *Ammonites* (*Cosmoceras*) *Parkinsoni*, a species almost confined to Dorsetshire; its associated forms are also mainly restricted to the same geographical area. Accompanying *Am.* (*Cosmoceras*) *Parkinsoni*, are *Am.* (*Cos.*) *garantianum*, *Am.* (*Opellia*) *Truellii*, *Am.* (*O.*) *subradiata*, *Am.* (*Sphæroceras*) *polymorphum*, *Am.* (*S.*) *dimorphum*, *Am.* (*Perisphinctes*) *Martinsii*, *Am.* (*Stephanoceras*) *Zigzag*. The following and associated Brachiopoda have also a wide distribution through the counties above named:—*Terebratula Phillipsi*, *T. sphæroidalis*, *T. Stephani*, *T. globata*, and *Rhynchonella spinosa*.

All the species of ammonites in the above four zones are of high specific value, both in Britain and on the Continent (France, Belgium, and Germany); and nearly 100 more might be added, all equally restricted as to stratigraphical range or time.

The highly developed Oolitic series of Gloucestershire becomes greatly reduced in thickness south of the barrier of the Mendip Hills; the corresponding beds in Dorsetshire do not exceed 50 feet, having lost or become attenuated in their southern extension nearly 250 feet (probably through differences of aerial sedimentation); their fauna is nevertheless the same as that of Somerset and Gloucestershire.

The following section shows the structure of Cleeve Hill north of Cheltenham, being, with Leckhampton, the key to the entire history of the Inferior Oolite:—

TABLE LX.—*Structure of Cleeve Hill.*

Zone of Cosmoceras Parkinsoni.	SUMMIT.	1. Trigonia grit . .	*Cosmoceras Parkinsoni*, *Perisphinctes Martinsii and corals*, *Thecosmilia gregaria*, *Thamnastræa*, *Isastræa*, &c. *Gryphæa sublobata*, *Pholadomya Heraultii*, *Lima probocidea*, *Opis cordiformis*, *Trigonia costata*, *Myopsis dilatata*, *Lima gibbosa*.
		2. Chemnitzia grit. .	*Chemnitzia procera Nerinæa*, 3 feet 6 in.

[1] We adopt the new nomenclature for the genera of ammonites instead of the single generic name *ammonites* for all species.

TABLE LX.—*Continued.*

Zone of Stephanoceras Humphresianus	Western Slope of the Hill	Rolling Bank.	3. Brachiopoda bed	*Terebratula Phillipsia, T. perovalis, Rhynchonella spinosa*, 2 feet 6 in.
			4. Road stone	*Stephanoceras Humphresianum, Pholadomya Heraultii, Chemnitzia Sœmanni, Trichitis undulatus* (40 species occur in this bed).
			5. Oyster bed	*Ostrea flabelloides, Lima Etheredgii, Pholodomya ovulum, Gressyla abducta* (20 species known in this bed).
		N. Quarry.	6. Yellow and Brown sands and nodules of sandstone	5 feet
			7. Hard wavy sandstone.	*Serpula socialis*. 3 feet
			8. Marly oolite	8 in.
			9. Upper Freestone.	*Terebratula fimbria* 12 feet
			10. Thin flaggy oolite	4 feet
		Upper Freestone Quarry.	11. Oolite marl[1] (fimbria bed)	*Lucina Wrightii, Terebratula fimbria, Myopsis punctata, Stomechinus germinans, Ceromya concentrica.*
			12. Thin hard bands of Limestone	1 foot 6 in.
			13. Thin beds of fine-grained oolitic Limestone	4 feet 6 in.
			14. Hard rubbly oolite marl	5 feet
Zone of Harpoceras Murchisonæ.			15. Lower Freestone—Upper terrace	26 ,,
			16. Lower Freestone—Lower terrace	40 ,,
			17. Hard beds of Pisolitic oolite	2 ,,
			18. Buff-coloured Pisolitic Limestone	4 ,,
			19. Roe stone	*Pseudodiadema depressum, Acrosalenia Lycettii, Trochotoma carinata* (35 species occur in this bed).
			20. Pea grit[2]	*Pygaster semisulcatus, Harpoceras Murchisoniæ, Patella rugosa, Hinnites velatus, Avicula complicata, Terebratula plicata* (60 species occur in this grit).
			21. Coarse ferruginous oolite.	

The fauna of the three zones of the Inferior Oolite of Gloucestershire, numerically given, shows the value and preponderance of the genera and species in each successive and continuous sedimentation; and taking Cleeve Hill as the type-section, it will form a basis for correlation or comparison with other sections in any given area, except for the Plantæ, none occurring in the Inferior Oolite of Gloucestershire, the estuarine series in Yorkshire possessing the only determined terrestrial flora.

[1] This bed may be the product of coral mud and other coral reef debris. *Vide* Q. Jour. Geol. Soc., vol. xvi. 1860.

[2] The Pea Grit varies considerably in development in different localities—Crickley, Leckhampton, and Cleeve Hill afford the best types of this bed.

TABLE LXI.—*Fauna of the Three Zones: Inferior Oolite.*

Classes.	Zone of Harpoceras Murchisonæ.	Zone of Stephanoceras Humphresianum.	Zone of Cosmoceras Parkinsoni.
Plantæ	...	...	...
Protozoa	...	...	...
Cœlenterata (Actinozoa)	$\frac{9}{10}$	...	$\frac{5}{6}$
Echinodermata	$\frac{9}{10}$	$\frac{1}{4}$	...
Annelida	...	$\frac{1}{3}$	...
Crustacea	...	...	...
Polyzoa	...	...	...
Brachiopoda	$\frac{3}{6}$	$\frac{3}{7}$	...
Pelecypoda	$\frac{26}{28}$	$\frac{13}{15}$	$\frac{11}{16}$
Gasteropoda	$\frac{13}{15}$	$\frac{3}{6}$	$\frac{4}{5}$
Ammonites	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$
Nautili	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$
Belemnites	$\frac{1}{1}$	...	$\frac{1}{1}$
Pisces	...	...	...
Reptilia	...	..	...
	$\frac{55}{93}$	$\frac{28}{61}$	$\frac{23}{30}$

The Cleeve Hill section, through the nine classes given above, shows the zonal fauna to be as follows—[1]

Zone of *Murchisonæ*	58 genera	and 93	species
„ *Humphresianum*	28 „	61	„
„ *Parkinsoni*	23 „	30	„

Northamptonshire.—No county in Mid-England offers greater facilities for the study of the Lower Jurassic rocks than Northamptonshire, standing, as the area does, midway between Oxfordshire and Yorkshire, on the line of strike of the Lower Oolites, and in the probable centre of many physical changes.

Five divisions are recognised in the Northamptonshire Oolites—*three* in the Lower division, and *two* in the Upper. The succession in descending order is as follows :—[2]

Upper Series.	1. Great Oolite Limestone.	
	2. Upper Estuarine series.	
Lower Series.	3. Lincolnshire Limestone.	
	4. Lower Estuarine series.	Northampton Sands.
	5. Ferruginous beds.	
	Upper Lias clay.	

[1] The Crustacea and Polyzoa are not given ; this may add 10 or 15 more species through the whole.

[2] The whole series is best developed in the four following localities :—Kingsthorpe, Northampton, Duston, and Blisworth. At Kingsthorpe 158 species have been collected ; at Duston, 93 ; and at Blisworth, 106.

The whole series has a thickness of about 130 feet. The Ferruginous or Ironstone beds of the Northampton Sands are doubtless upon the same horizon as the "Dogger" in Yorkshire, the Ferruginous beds of Glaisdale, and the Ironstones of the "Ridge" in Lincolnshire.

Neither the rich fauna nor the true position of the "Northampton Sands" was understood until Mr. S. Sharp showed their relation to those of Oxfordshire, then of doubtful stratigraphical position. The fauna of these ferruginous beds numbers 79 genera and 243 species,—the Pelecypoda alone including 42 genera and 144 species.[1]

Lincolnshire Limestone, or Great Limestone of the Inferior Oolite.

The Lincolnshire Limestone, or Great Limestone of the Inferior Oolite, consists of a series of cream-coloured marly limestones and oolitic rag-stones, 75 feet thick, constituting the so-called Stamford marble. The continuity of this limestone and its equivalents from Stamford is now determined beyond the Humber, where in the Cave area they form a marked feature, and terminate those beds in their southern physical aspects. North of this, much of their history is lost in the alternating conditions of the Lower Estuarine Oolites of Yorkshire. The interposition of the Lower and Upper Estuarine series, detected by Professor Judd, shows an important episode in the nature of the deposition and interpolation of these singular beds in the history of the Mid-England or Northamptonshire Oolites.

a. The Lower Estuarine belongs to the Inferior Oolite.

b. The Upper Estuarine to the Great Oolite.

Near Northampton these two fresh-water or Estuarine series come together. In Oxfordshire, the Upper series is traceable up to the "Stonesfield Slate."[2]

With the "*Collyweston Slates*," the Lincolnshire Limestone forms the upper part of the Inferior Oolite, and attains a thickness of about 200 feet. At Stamford the beds are about 80 feet thick.[3]

Facies of the Lincolnshire Limestone.—The Lincolnshire Limestones, in almost every locality where exposed, exhibit different characters. Prof. Judd recognised them under two aspects or facies, and designated these the "*Coralline facies*" and the "*Shelly facies.*" Compact, subcrystalline, argillaceous limestones, oolitic in texture and abounding in corals, characterise the first or "*Coralline beds*," which yield *Thamnastræa*, *Montlivaltia*, *Isastræa*, *Latimæandra*, *Theosmilia*, *Anabacia*, &c. An abundant molluscan fauna accompanies these corals, especially *Nerinæa* (*N. cingenda* and 10 other species), *Natica Leck-*

[1] *Vide* Q. Jour. Geol. Soc., vol. xxvi., 1870. No less than twenty carefully prepared lists of fossils accompany Mr. Sharp's second memoir. Q. J. Geol. Soc. vol. xxix, 1873.

[2] The difficulty experienced in separating the two Estuarine groups in Oxfordshire arose from the fact that the Northampton Sand was considered to be the equivalent of the Stonesfield Slate.

[3] In the north-west part of Lincolnshire the beds are divided into *Lincolnshire Limestone*, 36 feet thick, and *Stanton Oolites*, with a soft ferruginous bed at the base (Rev. J. E. Cross.)

hamptonensis, Eusepira canaliculata, Pleurotomaria armata, Phasianella (8 species), *Pholodomya fidicula, P. Heraulti, Ceromya Bajociana, Pinna cuneata, Mytilus Sowerbyanus, Rhynchonellæ* (14 species), and *Terebratulæ* (10 species), &c.

The second variety or type, the "*Shelly facies,*" is composed almost entirely of small shells, or fragments of shells, broken and eroded, accumulated under the influence of varying currents. They contain *Cerithium, Trochus, Monodonta, Turbo, Nerinæa, Astarte, Lima, Ostrea, Trigonia,* and remains of Echinodermata. There is an almost total absence of the Cephalopoda; two or three species of Belemnites and *Nautili* occur; and the Ammonites are reduced to four or five species. *Bel. acutus, B. Blainvillii,* and *B. canaliculatus,* with *Nautilus obesus, N. polygonalis* and the four Ammonites, *A. Blagdeni* (rare), *A. Murchisonæ,* var., *A. subradiatus,* and *A. terebratus,* constitute all the Cephalopoda yet known to occur in the Lincolnshire Limestone.

Accumulation and Conditions of Deposition.—The rocks of the two facies of the Lincolnshire limestone are not constant in their relative positions; and this change of conditions is doubtless due to difference of level of the sea-bed at the time of deposition. The great mass of the Lincolnshire oolite was accumulated under moderately-deep water; but both estuarine and littoral conditions prevail at its commencement and close during a portion of the Jurassic period, within the life province or area now constituting Britain, Northern France, and Western Germany. Local depression took place within an area having a diameter of something like 90 miles, the amount of depression being greatest within its centre. As a consequence of this local depression, there was slowly accumulated—by the growth of coral reefs, and the action of marine currents sweeping small shells and their fragments along the sea-bottom—a mass of calcareous strata, presenting many variations in its local characters, and constituting the formation to which has been applied the name of the "Lincolnshire Oolite Limestone." Again, wherever the junction of the Upper and Lower Estuarine series can be examined, there is proof of unconformity, and the thick series of beds of the Lincolnshire oolite is wedged in between them in a lenticular manner; the zone of *Am. Murchisonæ* holding the ferruginous Northampton Sands (certainly at the base), while the upper members possibly represent that of *Am. Sowerbyi.*[1] This clearly demonstrates that unconformity exists in the Midland area between the true Great Oolite series and the known top of the Lincolnshire limestone. Those beds in the Cotteswolds of Gloucestershire, &c., containing *Ammonites Parkinsoni* and *Am. Humphriesianus,* or the Fuller's Earth, the Ragstones, and Upper Freestones of the Inferior Oolite of that region, are entirely wanting in Northamptonshire and Lincolnshire.

Fauna of the Lincolnshire Limestone.—Careful research shows the extreme paucity of the Cephalopoda in the Northamptonshire and Lincolnshire deposits as compared with beds of the same age in

[1] The characteristic species of the zone of *Am. Sowerbyi,* an extensive one in the Inferior Oolite series, occur in this area of depression.

Gloucestershire, Dorsetshire, and Somersetshire. There are only two Nautili, *N. obesus* and *N. Polygonalis*, and two Dibranchiata, *Belemnites acutus* and *B. bessinus*. Still more striking is the dearth of the great group of the Ammonitidæ; only 3 species seem to occur, and these in one locality near Stamford: they are *Ammonites Murchisonæ*, *A. subradiatus*, *A. terebratus*. The Gasteropoda, with very few exceptions, are also different from any of the southern types, and differ equally from most of the Yorkshire forms. The Pelecypoda in both groups differ little from the southern facies, the large fauna in the Stamford area uniting many of the species. Compared also with Gloucestershire and Dorsetshire, the Brachiopoda are not abundant, and the same species prevail everywhere. Only one Polyzoon, *Cricopora* or *Spiropora straminea*, occurs, and this well-known form is found in the Millepore-beds of Yorkshire. The Echinoidea, species for species, are the same as those occurring all through the Cotteswolds; they equally help us to fix the age of the Cave beds north of the Humber, determining them to be but an extension of the Lincolnshire Oolite across that estuary.[1]

Freestone Beds.—The *freestone* beds of the south-west of England exhibit the same paucity of fossils, and evidently were originally deposited under similar conditions. It is clear that the great mass of the Lincolnshire Oolite was accumulated under moderately deep-water conditions. The lower members, however, exhibit transitional conditions towards those of the underlying Estuarine series. The Arenaceous beds contain much wood and the remains of ferns, especially *Polypodites Lindleyi*, Göpp. (*Pecopteris polypodioides*, Lindl.), the whole resembling the conditions prevailing in the Lower Sandstones and Shales of east Yorkshire. It is at the base of these arenaceous beds that the fissile "Collyweston Slates" occur, whose position was long misunderstood, being wrongly assigned to the horizon of the Stonesfield Slate below the Great Oolite. That these slaty beds were accumulated under littoral conditions, or in close proximity to the shore, their fossil contents clearly prove.

Characteristic Local Fauna of the Freestone Beds.—Upwards of 50 species characterise these slates. No mammalian, reptilian, or insect remains (so characteristic of the Stonesfield Slate) have occurred; nor do we know of any Brachiopoda. One important univalve, "*Pterocera Bentleyi*," essentially characterises the deposit; it ranges into the limestone above, but is rare. The characteristic bivalves are *Grevillia acuta*, *Pinna cuneata*, *Trigonia compta*, *Lucina Wrightii*, *Myacites scarburgensis*, *Cardium Buckmani*, *Pholadomya fidicula*, and *P. ovalis*. *Pecten lens* and the beautiful fern *Polypodites Lindleyi*

[1] In the appendix to Professor Judd's memoir by Mr. Etheridge will be found, on pp. 276–283, a detailed specific list of every species then known as occurring in the Lincolnshire Oolite, Collyweston Slate, and Northampton Sand. The faunas of these 3 groups or horizons are compared amongst themselves, then with the Inferior Oolite in the south of England and Yorkshire, and lastly with the Great Oolite of the west of England. The result of this analysis is an important one, and clearly shows that the Lincolnshire beds are far more nearly allied to those of the south of England than to the Yorkshire Oolites.

specially distinguish these "Collyweston slates." Numerically the fauna is thus expressed:—

		Genera.	Species.
Gasteropoda		5	6
Dithyaria	Pelecypoda	12	26
Monomyaria	Pelecypoda	10	20
Asteroidea		1	1
		28	53

Collyweston Slate.[1]—The fissile calcareous sandstones or slates, which so much resemble the Stonesfield Slate of the Cotteswolds, and which were placed upon the same horizon by early observers, are now clearly shown to rest immediately upon the Northampton Sands, and below that division of the Inferior Oolite now termed the Lincolnshire Limestone. It is probable that they may represent the Lower Estuarine Shales of the Yorkshire coast,[2] which overlie the Dogger. That the Collyweston beds were accumulated under littoral conditions, or in close proximity to the shore, their fossil contents clearly show. The surface of the slates exhibits ripple-marks, annelid-tracks and burrows; and, like the Stonesfield Slate, numerous plant-remains.

Fauna of the Collyweston Slate.—The most characteristic shells are *Pterocera Bentleyi*, *Natica Leckhamptonensis*, and *Patella rugosa*, *Gervillia acuta*, *Pinna cuneata*, *Trigonia compta*, *Lucina Wrightii*, *Pholadomya fidicula*, *Pecten lens*, and *Hinnites abjectus*, &c. The fauna is entirely molluscan. The occurrence of slaty beds in the Oolite rocks is a phenomenon of very local character. Professor Judd (in his "Introductory Essay to the Geology of Rutland") gives the following tabular view of the slate beds known in the Lower Oolites of this country:[3]—

Great Oolite.	Slates of Fairford, Chevenage, &c.	Forest Marble.
	Slates of Stonesfield, Eyeford, Sevenhampton Common, &c.	Base of Great Oolite.
Inferior Oolite.	Slate of Bransby (Yorkshire)	Middle part of Inferior Oolite (zone of *Ammonites Humphresianus*).
	Slates of Collyweston, Kirby, Dene Park, &c.	Lincolnshire Oolite (zone of *Ammonites Sowerbyi*).
	Slate of Duston	Northampton sand (zone of *Ammonites Murchisoniæ*).

[1] Collyweston, near Stamford. These slates have been quarried for roofing purposes for the past 400 years.

[2] "The Lower Shale and Sandstone," with no marine fossils; 25 genera and 55 species are known from these slates.

[3] Mem. Geol. Surv. England and Wales; Geol. of Rutland, &c., p. 6.

PLATE XXI.

LOWER JURASSIC FOSSILS.

1. *Isocardia* (*Ceromya*) *concentrica* (Sow.) Inferior Oolite. Gloucestershire and Yorkshire.
2. *Perna quadrata* (Sow.) Cornbrash and Great Oolite. Gloucestershire, &c.
3. *Astarte elegans* (Sow.) Inferior Oolite. Somerset, Cotteswold Hills, Yorkshire.

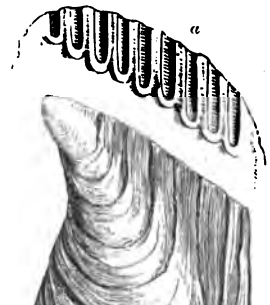
3a. *Astarte Voltzii.* Inferior Oolite.

4. *Pseudodiadema seriale?*
5. *Pygaster semisulcatus* (Phill.) Inferior Oolite. Leckhampton, Crickley, Stroud, &c. &c.
6. *Echinobrissus clunicularis* (Llhwyd.) Inferior Oolite. Wilts, Yorkshire, Dorset, Northampton.
7. *Collyrites bicordatus* (Desor.) Dorset, Somerset, &c.
8. *Rhynchonella cynocephala* (Richard). Inferior Oolite. Gloucestershire.
9. *Belemnites sulcatus* (Miller). Inferior Oolite. Dundry, &c.

PLATE XXI.

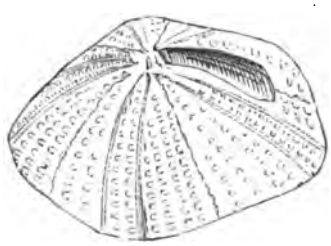
LOWER JURASSIC FOSSILS.

1



2

4



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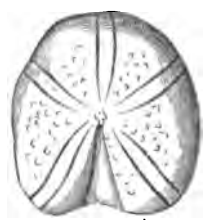
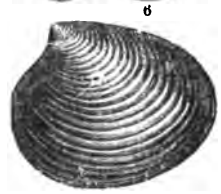
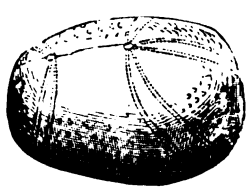
9



6



3



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3a

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CHAPTER XXXVII.

PALÆONTOLOGY OF THE INFERIOR OOLITE ROCKS AND FULLER'S EARTH.

Plantæ.—The Jurassic Plantæ number 60 genera and 186 species, 41 genera and 130 species of which are confined to the Inferior Oolite, not one, so far as we know, passing the upper limits of that formation. The remaining 56 species chiefly range through the Lias, Great Oolite, and Coral Rag. Almost every species occurs in the estuarine shales and sandstones of the Yorkshire coast, either in the Scarborough or Whitby area. The Middle Shales and Sandstones contain 17 genera and about 50 species, the Lower 13 genera and 30 species. The chief genera are *Otozamites*, 10 species, *Pecopteris* 22, *Phlebopteris* 8, *Pterophyllum* 9, and *Sphenopteris* 16. In Yorkshire the *Filicæ* are illustrated by 53 species, the *Cycadaceæ* by 23, and the *Coniferæ* by 7. There is no other locality in the British Islands where such an assemblage of Jurassic plants can be studied. No complete plant is known in the Forest Marble; but innumerable fragments of coniferous wood occur in the flaggy beds of which it is chiefly composed. Nor is any species known from the Fuller's Earth, Cornbrash, or Kellaways Rock.

At Stonesfield in Oxfordshire, and Eyeford and Sevenhampton in Gloucestershire, the Stonesfield "slates" occur as a thin band beneath the true Great or Bath Oolite; and in them, especially near Oxford, an abundant flora has been obtained. Professor Phillips, in his work "On the Geology of Oxford and the Valley of the Thames," enumerates, figures, and describes a large and interesting flora, comprising nearly 40 species.

The remarkable cones *Aroides Stutterdi*, Carr., and *Kaidacarpum ooliticum*, Carr., are both from the Stonesfield beds.

Protozoa.—Eight genera and 8 species are known, all of which are confined.

Cœlenterata.—*Actinozoa.*—The Actinozoa of the Inferior Oolite stand almost alone, its 48 species being, with but few exceptions, confined to it. Next to the Lower Lias the Inferior Oolite is richer in species than any other Jurassic group. The only species that pass to higher beds are *Anabacia hemisphærica*, *A. orbulites*, *Comoseris vermicularis*, *Isastræa explanata*, *I. explanulata*, *I. limitata*, *Montlivaltia Delabechei*, *M. tenuilamellosa*, *Stylina solida*, and *Thamnastræa concinna*. Eight of these 10 do not pass beyond the Great Oolite. Thus, out of the 19 genera and 48 species that commence in the Inferior Oolite, 5 genera and 7 species pass to the Great Oolite. With the exception of *Isastræa* and *Thamnastræa*, most of the Corals are simple forms, *e.g.*, *Montlivaltia*, *Anabacia*, *Cyclolites*, *Trochocyathus*, &c. In Yorkshire but few species occur in the In-

ferior Oolite, *Gonioseris angulata*, *G. Leckenbyi*, and *Montlivaltia convexa* being all that are there known.

Echinodermata.—In the whole of the Jurassic rocks, including the Lias, there are 43 genera and 206 species. The Inferior Oolite contains 22 genera and 51 species; 7 genera and 10 species pass to the Fuller's Earth, 8 genera and 11 species to the Great Oolite, 2 genera and 2 species to the Forest Marble, and 3 genera and 5 species to the Cornbrash. The whole Jurassic rocks yield 9 genera and 37 species of Crinoidea, 14 genera and 35 species of Asteroidea, and 19 genera and 129 species of Echinoidea.

Crinoidea.—Only 2 species of the known 37 occur in the Inferior Oolite; they are *Pentacrinus Milleri* and P. *Austenii*.

Asteroidea.—*Astropecten* with 3 species, *Goniaster* with 2, *Solaster* and *Stellaster* each with 1, comprise the whole of the Starfishes of the Inferior Oolite.

Echinoidea.—Seventeen genera and 40 species out of the 129 known occur in the Inferior Oolite. Eleven genera and 25 species belong to the group Endocyclica, and 6 genera and 15 species to the Exocyclica.

Annelida.—*Serpula*, with 9 species, and *Vermicularia* and *Vermilia* with one in each, constitute the Annelidan fauna of the inferior Oolite. *Vermilia sulcata*, *Serpula socialis*, and *S. limax* are also Lower and Upper Lias. None of the 11 species pass to higher horizons.

Crustacea.—The only Decapod known is *Glyphea rostrata;* and this Macruran ranges up to the Coralline Oolite.

Polyzoa.—Seven genera and 17 species occur, viz., *Berenicea* 1 species, *Ceriopora* 2, *Diastopora* 9, *Heteropora* 2, *Spiropora* 1, *Stomatopora?* 1, and *Theonoa* 1 species.

Brachiopoda.—Ten genera and 90 species range through the Inferior Oolite. The following species also occur in the Upper Lias:—*Discina orbicularis*, *Lingula Beanii*, *Rhynchonella plicatella*, *Terebratula infra-oolitica*, *T. sphæroidalis*, *Thecidium Bouchardi*, *T. triangulare*, and *T. Deslongchampsii*.

Pelecypoda (Lamellibranchiata).—The Inferior Oolite contains by far the richest fauna in the 13 stratigraphical horizons of the Jurassic system, and has yielded 342 species in both groups (106 Monomyaria and 236 Dimyaria). The importance of a knowledge of the Mollusca as an aid to stratigraphical geology, and of the value of species (regard them how we may) as factors in the identification of strata—however different petrologically, and however distant—is familiar to all students. In no group of rocks is more critical knowledge required for the discrimination of contemporaneous and homotaxial strata than in the Jurassic series. In Europe the Molluscan fauna of the Jurassic group is one and the same through each of its subdivisions. The fauna of the Lias of England, Scotland, Ireland, France, and Germany, is almost identical, zone for zone. When the species in the larger genera are critically examined, their universality and continuity are remarkable and striking.

Monomyaria.—Fifteen genera and 106 species are known in the Inferior Oolite, only 13 of which passed up from the Lias. It is important to know those forms which unite the two horizons, especially as so complete a change in the fauna occurred at the close of the Lias and commencement of the Inferior Oolite. This group, as we have seen, was represented in the Lias strata by 18 genera and 114 species in the Lower, 16 genera and 60 species in the Middle, and 13 genera and 32 in the Upper Lias, and 13 of these latter lived on into the more calcareous waters of the Inferior Oolite sea. The connecting species are *Avicula inæquivalvis, Gervillia Hartmanni, Hinnites abjectus, H. velatus, Lima bellula, L. electra, L. punctata, Pecten articulatus, P. comatus, P. demissus, Perna rugosa, Pinna fissa*, and *P. Hartmanni.* Six genera and 8 species pass up into the Fuller's Earth, which is fairly developed in the Stroud valley, the Bath area, and parts of Somerset; 12 genera and 33 species connect the Inferior and Great Oolite; and no less than 11 genera and 18 of the same species range to the Cornbrash. Community of species between the Inferior Oolite and Cornbrash could hardly have occurred in the Yorkshire basin, owing to the broken sequence between the Dogger and the Cornbrash—the Grey or Scarborough Limestone, and the Millepore beds, being the two marine series in the midst of the Estuarine beds. The long-range species are *Avicula braamburiensis, A. Münsteri, Gervillia acuta, Hinnites abjectus, Lima duplicata, L. pectiniformis, Ostrea acuminata, O. flabelloides, Pecten annulatus, P. crenatus, P. demissus, P. lens, P. personatus, Perna rugosa, Pinna cuneata*, and *Placunopsis inæqualis.* These 16 species, if not as good witnesses as the rarer forms, show that the conditions were such that only minor physical changes affected the fauna during the intervals of time which occurred between the different horizons or sedimentations. Six genera and 9 species pass to the Kellaways Rock, and 3 genera and 8 species to the Oxford Clay, viz., *Avicula inæquivalvis, Lima duplicata, L. pectiniformis, Pecten annulatus, P. crenatus, P. demissus, P. lens*, and *P. vimineus*, all moderately deep-sea forms. The Corallian beds contain 3 of those just quoted, with *Placunopsis inæqualis, Ostrea solitaria*, and *O. flabelloides.* The Kimmeridge Clay, through the persistent shells *Avicula (monotis) inæquivalvis, Ostrea solitaria, Pecten crenatus, P. articulatus, P. demissus*, and *P. vimineus*, keeps up the connection or continuity; *but no species* of any Jurassic group passes the Portland beds.

Dimyaria.—Seventy genera and 924 species of this group are known in the whole of the Jurassic rocks, and 47 genera and 236 species occur in the Inferior Oolite. Of these species 28 pass to the Fuller's Earth, 71 to the Great Oolite, 8 to the Forest Marble, 20 to the Cornbrash, 8 to the Kellaways Rock, 2 to the Oxford Clay, and 8 to the Corallian beds. The genera most largely represented are—*Astarte* with 24 species, *Arca* 12, *Cucullæa* 16, *Modiola* 9, *Myacites* 11, *Mytilus* 9, *Pholadomya* 11, *Tancredia* 10, *Trigonia* 34. Thus these 9 genera out of the known 47, and 136 species out of 236, constitute more than one half of the Dimyarian fauna of the Inferior Oolite. Assuming that the species in the above nine prolific genera

would probably have a long range in time, we find that the following in the same genera pass to the Great Oolite—in *Astarte* 10, *Arca* 4, *Cucullæa* only 2, *Modiola* 5 out of 9, *Myacites* only 1, *Mytilus* only 1, *Pholadomya* 4, *Tancredia* 5, and *Trigonia* only 4 out of 34; or 36 species out of the 136 in the above genera are common to the Great and Inferior Oolite.

Gasteropoda.—The whole of the Jurassic Gasteropoda number 76 genera and 1005 species; and those of the Inferior Oolite 41 genera and 240 species. Only 6 genera and 6 species are common to the Lias and to the Inferior Oolite, thus a totally new Gasteropod fauna, numbering 234, occurs; and, beyond the fact that 22 genera and 40 species are common to it and the Great Oolite, the species are almost confined to the inferior division. Only one species (*Alaria Phillipsii*) seems to unite the Fuller's Earth with the Inferior Oolite. The largely represented genera are *Alaria* with 19 species, *Cerithium* 10, *Chemnitzia* 9, *Nerinæa* 12, *Pleurotomaria* 47, *Trochus* 20, *Turbo* 17. The rarer genera are sparingly represented—*Bulla*, *Ceritella*, *Cirrus*, *Crossostoma*, *Fissurella*, *Melania*, *Onustus*, *Pileolus*, *Pterocera*, *Scalaria*, *Solarium*, and *Spinigera*. Only 3 species pass to the Kellaways Rock, viz., *Pleurotomaria granulata*, *Natica punctura*, and *Alaria trifida*, and only the last species passes to the Oxford Clay; while *Turbo funiculatus* is the only known form common to the Coral Rag and Inferior Oolite.

Cephalopoda.—*Ammonites.*—Only 42 species occur in the Inferior Oolite; yet the Lias holds 293 species, 3 of which pass to this horizon—*Harpoceras concavum*, *Harpoceras radians*, and *H. insigne*, and only one species of the 42 (*Am. fuscus*) passes to higher beds. This restriction is remarkable and, on stratigraphical grounds, important. These 42 species occupy the three zones of *Murchisonæ*, *Humphriesianus*, and *Parkinsoni*, these zonal types definitely holding their position or horizons in the Inferior Oolite; and whether the beds are largely developed or not, their succession is everywhere the same throughout Britain and the Continent. No group of the Mollusca is so constant in distribution or so valuable to the stratigraphical geologist; but side by side with the Ammonites we may place the Echinoidea as equivalent in value, and equally reliable stratigraphically. Besides the true Ammonites, one species of *Ancyloceras* (*A. annulatum*) occurs in the Inferior Oolite.[1]

Nautili.—The 6 species of *Nautili* that occur in the Inferior Oolite are all confined to it.

Belemnites.—We have stated that 112 species are known in the British Jurassic rocks, but only 16 species occur in the Inferior Oolite; two horizons above this, the Fuller's Earth and Great Oolite, yield only 3 species each; none are known in the Forest Marble and Cornbrash.

[1] *Ancyloceras annulatum* is the only species in the Inferior Oolite; and the Kellaways and Oxford-Clay species, *A. calloviense*, completes our knowledge of the non-involute forms of the Jurassic Ammonitidæ.

TABLE LXII.—*Analysis and Distribution of the Inferior Oolite Species.*

From Lias.	Classes.		Genera.	Species.	Fuller's Earth.	Great Oolite.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Coral Rag.	Kimmeridge Clay.	Portland Oolite.
		Plantæ	41	130									
		Protozoa	8	38									
		Rhizopoda	none.										
		Cœlenterata	19	48									
		Echinodermata	22	51									
		Annelida	3	11									
		Crustacea	2	2									
		Bryozoa	7	17									
		Brachiopoda	10	90									
	62 genera and 342 species. Pelecypoda.	Monomyaria	15	106									
		Dimyaria	47	236									
		Gasteropoda	41	240									
	Cephalopoda.	Ammonites	1	42									
		Ancyloceras	1	1									
		Nautili	1	6									
		Belemnites	1	16									
		Teuthidæ	none.										
		Pisces	2	4									
		Reptilia	none.										
		Mammalia	none.										
			221	1008									

Pisces.—*Hybodus crassus, Strophodus magnus, S. subreticulatus,* and *S. tenuis* are all that we actually know of the Inferior-Oolite fish. No Pycnodont or Lepidotoid form, as we should almost expect, has ever been obtained from the Inferior Oolite.

Reptilia.—Thirty-two genera and 130 species range through the whole Jurassic formation. The Fuller's Earth and Kellaways Rock appear to have none. Thirteen genera and 27 species occur in the Great Oolite, 3 genera and 3 species in the Forest Marble, and one species in the Cornbrash. The Oxford Clay contains 13 species, the Corallian rocks 3, the Kimmeridge Clay 43, and the Portlandian 6 species. We state these now, to show the census of the Reptilia through the Jurassic rocks; individually they will be noticed hereafter.

Mammalia.—None known.

Fuller's Earth.

The Fuller's Earth.—This argillaceous deposit forms a transition series between the Inferior and the Great Oolite, and is shown in its entire thickness in the Cotteswold Hills, and in the neighbourhood of Stroud and Bath. It is a variable member of the Jurassic series, the term being applied to a thick deposit of blue and yellow clay (Fuller's Earth), which is opaque, soft, and unctuous. In Somersetshire, its thickness is from 120 to 150 feet, and in Dorsetshire 400 feet; it entirely disappears north of Gloucestershire.[1]

Fauna.—The characteristic fossils are *Ostrea acuminata, Pecten vagans, Goniomya literata, Homomya Vezelayi, Ceromya concentrica, C. plicata, Terebratula ornithocephala, T. globata,* and *Rhynchonella varians.*

Only 51 genera and 110 species occur in this division of the Lower Oolites. Seeing that 35 of the 51 genera and 65 of the 100 species were derived from the Inferior Oolite, and that 80 per cent. of the species occurring are also common to the succeeding Great Oolite, this division has no value, save on physical grounds, and this only over a very limited area; for the Fuller's Earth is by no means universal or even general in its distribution. No Plantæ, Amorphozoa, Crustacea, Nautili, Teuthidæ, or Reptilia occur, *i.e.*, 9 of the 14 classes are unrepresented. The value, therefore, of the Fuller's Earth as a life-group is almost *nil;* it is only through the Echinodermata and the Pelecypoda that it has position; and 50 per cent. of these are Inferior Oolite species. The Fuller's Earth is an extremely local formation, the Stroud valley near Gloucester and Bath being the only places where it is extensively developed as a purely argillaceous deposit; in Somersetshire it merges on its strike into a calcareous deposit termed the "Fuller's Earth Rock."

Cœlenterata.—*Anabacia hemisphærica, Montlivaltia Delabechei, M. tenuilamellosa,* and *M. Wrightii,* are the 4 species known.

[1] The Fuller's Earth near Cheltenham is a mere thin band of clay; near Stroud it is 70 feet thick; near Wootton-under-Edge 128 feet; and at and near Bath 150 feet thick.

Echinodermata.—One species only belongs to the Fuller's Earth, viz., *Pygurus Michelini*, and this ranges up to the Cornbrash. *Acrosalenia spinosa*, *Clypeus Plottii*, and *Pygurus Michelini* pass to the Great Oolite; the same 3 species appear in the Forest Marble, and 2 in the Cornbrash.

Annelida.—*Serpula triangulata*, *S. lævigata*, and *S. tricarinata* occur; the first two pass to the Great Oolite.

Crustacea.—None.

Polyzoa.—*Diastopora cricopora*, *D. oolitica*, and *Terebellaria ramosissima* constitute the Polyzoan fauna. These same species pass to the Great Oolite, in which division there are 16 genera and 31 known forms.

Brachiopoda.—Only 4 genera and 14 species occur. The genus *Terebratula* has yielded 5 species, *Waldheimia* 4, and *Rhynchonella* 1.

Pelecypoda (Lamellibranchiata).—*Monomyaria.*—More than 50 per cent. of this group of the Bivalvia pass up from the Inferior Oolite; for out of the 9 genera and 15 species occurring, 6 genera and 8 species are common to the two formations.

The long-range forms are *Avicula echinata*, *Gervillia acuta*, *Lima duplicata*, *L. gibbosa*, *Ostrea acuminata*, *O. Sowerbyi*, and *Pecten vagans*. Many species range from the Inferior Oolite to the Corallian beds, but do not appear in this argillaceous series. The Ammonites dwindled from 42 species in the Inferior Oolite to 5, the Gasteropoda from 41 genera and 240 species to *one genus and one species* (*Alaria Phillipsii*), and the Pelecypoda from 62 genera and 476 species to 18 genera and 36 species, the Dibranchiate Cephalopoda through the Belemnites from 16 species to 3. This decrease from so prolific a fauna could only be due to physical causes; probably a local deep-sea condition prevailed at the close of the Inferior Oolite period, and with it took place a corresponding migration of those species fitted to the new condition of things.

Dimyaria.—Twenty-two genera and 51 species are known, 28 of which are Inferior Oolite, so that, as in the group Monomyaria, 50 per cent. passed up from the beds below. These are chiefly moderately deep-sea forms, such as *Trigonia*, *Thracia*, *Pholadomya*, *Nucula*, *Myacites*, *Modiola*, *Homomya*, *Cucullæa*, *Anatina*, &c. Nineteen genera and 36 species passed to the Great Oolite.

Gasteropoda.—It seems incredible that a subformation standing between two such prolific horizons as the Inferior and the Great Oolite (the former possessing 240 species, and the latter 247) should *yield only one species* (*Alaria Phillipsii*) which bridged over the time occupied in the deposition of the Fuller's Earth clays; this form first appeared in the Inferior, and died out in the Great Oolite. Yet 40 species somewhere lived on from the Inferior Oolite during the long epoch, and appeared again in the Great Oolite; such a total removal or local migration of a great group is unparalleled in the British Secondary rocks during any period of their long history.

Cephalopoda.—*Ammonites.*—*Am. biflexuosus*, *Am. discus*, *Am. fuscus*, *Am. Herveyi*, and *Am. viator* are the only 5 species known.

The zone of *Am. Parkinsoni* did not transmit its rich contents to the Fuller's Earth; individuals, like species, sparingly occur in these beds. *Am. discus* passes to the Great Oolite and Cornbrash, and *Am. Herveyi* to the latter and the Forest Marble.

Nautili.—None known.

Belemnites.—*B. Blainvillii*, *B. parallelus*, and *B. spinatus* are all that are known of the Dibranchiata. *B. spinatus* passes to the Great Oolite.

No Fish, Reptilia, or Mammalia are known to occur in the Fuller's Earth.

CHAPTER XXXVIII.

GREAT OR BATH OOLITE AND STONESFIELD SLATE.

THE rocks of this division of the Lower Jurassic series have an extensive range across England from Somersetshire to Lincolnshire, but not with the same continuity as the Inferior Oolite and its subdivisions. It forms a well-marked feature in Gloucestershire, Wiltshire, and Oxfordshire, and consists of two groups of strata:—[1]

1. LOWER GROUP. Composed of shelly, yellow or cream-coloured oolitic limestones, with partings of marl or clayey shales (*The Great Oolite proper*), and the Stonesfield Slate at the base.
2. UPPER GROUP. Consisting of clays and shelly limestones, including the Bradford Clay, Forest Marble, and Cornbrash.[2]

Subdivisions of the Great Oolite.—The four members or subdivisions of the Great Oolite of the Midland district are:—

Lower.	*a.* The Upper Estuarine series.	Midland District.
	b. The Great Oolite Limestone.	
Upper.	*c.* The Great Oolite Clays.	
	d. The Cornbrash (Limestone).	

a. The Upper Estuarine is on the same horizon as the Stonesfield Slate.

b. The Great Oolite Limestone is an extension of the calcareous group of the south.

c. The Great Oolite Clays represent the Forest Marble and Bradford Clay.

d. The Cornbrash is the same distinct stratum so well known all through England.

[1] Including the Stonesfield Slate at the base, with some authors, it would form three divisions.

[2] In Yorkshire and in North Lincolnshire the Cornbrash stands alone. There is no representative of the Bath Oolite in Yorkshire, and there the Cornbrash is the most persistent Zone of the whole Lower Jurassic (Oolitic) group, both lithologically and palæontologically.

These divisions demand from the palæontologist careful analysis. The Limestones are eminently characterised by their special faunas. Everywhere in this area *Ostrea Marshii*, *Echinobrissus clunicularis*, *Avicula echinata*, *Gervillia aviculoides*, *Terebratula obovata*, *T. ornithocephala*, *Ammonites macrocephalus*, *A. Herveyi*, and *A. discus* characterise the Cornbrash. The Great Oolite forms are equally distinct and important — *Ostrea Sowerbyi*, *O. subrugulosa*, *Clypeus Milleri*, *Terebratula maxillata*, *Rhynchonella concinna*, *Homomya gibbosa*, *Nautilus Baberi*, *N. hexagonus*, and *N. subtruncatus* being in this group the dominant forms.

a. **Midland Upper Estuarine Series.**—Nothing in the south and south-west of England resembles these beds; they show an alteration of marine and fresh-water conditions, such as would now take place under slow elevation or depression in the estuaries of rivers: few fossils accompany these clays and sands; they cover but small areas, and often occur in "*pipes*" let down into the underlying strata.[1]

b. c. **Great Oolite Limestone and Clays.**—The upper Zone of the Great Oolite, as elsewhere in England, is remarkably uniform in character in its range from Gloucestershire to Mid-Lincolnshire; in the latter area it thins out, and finally disappears before reaching the Humber. A considerable proportion of the species also occurs in the Cornbrash, no less than 119 uniting the Cornbrash proper with the Great Oolite of the Midland district. The chief fossil localities are of necessity those in which the type-forms exist. The Echinodermata found in the Great Oolite are only *Echinobrissus clunicularis*, *E. sinuatas*, and *Pygaster semisulcatus;* no Crustacea, Polyzoa, Ammonites, or Belemnites have been recorded, and only one *Nautilus* (*N. Baberi*). On the other hand, the Pelecypoda are numerous, the Great Oolite areas yielding a recurrent fauna of 75 genera and 190 species. We know only of 5 species of Gasteropoda, *Natica neritoidea*, *N. globosa*, *Nerinæa funiculus*, *N. Voltzii*, and *Monodonata*. The Brachiopoda are individually numerous, but the species few.

The absence of corals may account for the non-oolitic character of the Great Oolite Limestones, a marked feature throughout the series under notice.

d. **Cornbrash.**—It is doubtful whether the Cornbrash of Yorkshire is on precisely the same horizon as that of Lincolnshire and Northamptonshire. It retains its general and uniform limestone character from Dorsetshire and Gloucestershire, and disappears under this condition before reaching the Humber.

These subdivisions are not present everywhere, but appertain mostly to Wiltshire, Gloucestershire, and part of Oxfordshire, where the Great Oolite is traceable from Woodstock and Burford into Northamptonshire, yielding on its way near Oxford a remarkable fauna. It continues under varying conditions into the middle of Lincolnshire; it there thins away, or is lost upon its strike, and does not cross the Humber into Yorkshire.

[1] See the clear description of these beds in Professor Judd's memoir, *loc. cit.* pp. 188–200, with reference to sheet 64 of the Geological Survey map.

Stonesfield Slate.

This thin but important deposit occurs immediately below, or at the base of, the Great Oolite, and is rich in fossil Plants, Echinodermata, Mollusca, Fish, Reptilia, and Mammalia. It is chiefly composed of a hard fissile calcareo-siliceous sandstone or flagstone, which readily splits along the planes of bedding; near Burford and Windrush the slate passes into, or becomes an Oolitic Freestone. This is the lowest zone of the Great Oolite.

Fauna and Flora.—The fauna and flora of the Stonesfield Slate are remarkable, and many species are identical with those in the higher zones in the Great Oolite.[1]

A large and fine assemblage of plants, all of which were evidently derived, ranges through the Slates. Among the Ferns there are 6 genera—*Cyclopteris, Glossopteris, Hymenopteris, Pecopteris, Sphænopteris,* and *Tæniopteris.* Of the MONOCOTYLEDONS, *Aroides, Benzonia, Lilia, Naiadites,* and *Stricklandia* occur. The important group of the Cycadeæ is represented by 10 species, 8 of which are Palæozamiæ with *Bucklandia squamosa.* The Coniferæ are represented by *Taxites* and *Thuytes.* The Fauna numbers 94 genera and 172 species. The Reptilia are *Testudo Stricklandi, Ichthyosaurus advena, Plesiosaurus erraticus, Teleosaurus brevidens, T. subulidens,* and *Rhamphorhynchus Bucklandi.*[2]

Palæontology.—The characteristic fossils are *Ostrea Sowerbyi, Terebratula maxillata, Rhynchonella obsoleta, Gervillia acuta, Pecten fibrosus, Trigonia impressa, Unicardium gibbosum, Pholadomya acuticosta, Nucula Ibbetsoni, Phasianella elegans, Amberlya nodosa, Belemnites ari-pistillum,* and *Ammonites Waterhousii.* All these species occur abundantly, and on the surfaces of the slates.

The most remarkable remains in the Stonesfield fauna are the mammalian, no less than 10 lower jaws of insectivorous marsupial mammals having occurred in this thin deposit, illustrating 4 genera—*Amphilestes, Phascolotherium* (which were probably insectivorous), *Amphitherium,* and *Stereognathus. Amphitherium* would appear to have been insectivorous, and nearly allied to the Australian *Myrmecobius,* or banded ant-eater. *Stereognathus* may have been marsupial, but Prof. Owen is disposed to regard it as "placental, hoofed, and herbivorous."[3] *Phascolotherium,* through its dentition (molar and premolar), shows remarkable agreement with the living American *Polyprotodont* Opossums (*Didelphidæ*), a family of marsupials now living in North and South America. This marsupial American type is the Dryolestes, from the Jurassic rocks of North America; and the Postpliocene deposits of the same continent have yielded bones referable to the living *Didelphys.*

The discovery of these small fossil mammalia (including the Triassic *Microlestes,* the earliest form yet in existence) has had greater influence in the course of geological opinion than even that of the

[1] See Morris and Lycett: "Mono. Great Oolite Fossils" (Pal. Soc.), 1850 and 1855.

[2] See Phillip's "Geol. of Oxford and the Valley of the Thames," 8vo, 1871, pp. 167–180; and Buckman, "Geol. of Cheltenham" (Eyeford Foss.)

[3] The original jaw of *Stereognathus ooliticus* is in the Museum of Practical Geology, Jermyn Street. See Owen's "British Fossil Mammals," p. 62; also "Palæontology," 2d ed., p. 348.

huge contemporaneous reptiles; they were the first-discovered proofs of the existence of warm-blooded mammalia as far back in time as the Upper Triassic period. The lacustrine or Estuarine strata of Purbeck add still more to their history, for from the Purbeck beds have been exhumed upwards of 20 species belonging to 11 genera—*Spalacotherium*, *Amblotherium*, *Peralestes*, *Achyrodon*, *Peraspalax*, *Peramus*, *Stylodon*, *Bolodon*, *Triconodon*, *Triacanthodon*, and *Plagiaulax*, this last resembling the Australian kangaroo rat (*Hypsiprimnus*).[1] Associated with these Stonesfield Slate mammalia are Reptilia, including *Megalosaurus*, *Teleosaurus*, and *Testudo*; also Fish—*Pholidophorus*, *Lepidotus*, *Pycnodus*, *Ganodus*, *Hybodus*, *Nemacanthus*, *Pristacanthus*, *Strophodus*, and *Asteracanthus*.

The Stonesfield slaty or flaggy beds are also worked in the Evenlode valley at Sarsden and Woodstock; on Sevenhampton Common, Eyeford, &c., and the thicker freestone building beds at Burford and Windrush. The shelly freestones at Minchinhampton Common become northwards fissile, shelly, or sandy, lose their calcareous character, and become argillaceous, passing into beds of estuarine condition, presenting alternations of fresh-water and marine strata and fossil remains. These strata in North Northamptonshire and Lincolnshire are the Upper Estuarine shales of the Geological Survey, and form the base or lower zone of the Great Oolite. Further south still in Lincolnshire these upper estuarine beds become gradually reduced in thickness—the thinning away of the Great Oolite resulting in the two argillaceous series *representing the Forest marble* and *Stonesfield slate* being brought together; thus the only remains of the Great Oolite series below the Cornbrash in North Lincolnshire is a thin series of clays of more or less estuarine character.

Development of the Great Oolite.

Physical Changes South of the Humber.—These changes south of the Humber have resulted in the entire loss of the Fuller's Earth, Stonesfield Slate, and Great Oolite in the Yorkshire series, all below the Cornbrash being the great succession of the lower and upper Estuarine sandy and coaly shales between the Dogger and the Cornbrash and Kellaways series—alternations of level during the sedimentation of the Yorkshire Estuarine beds or Inferior Oolite having allowed of the deposition of two well-defined marine groups—the *Millepore beds* and *Grey or Scarborough Limestone*, both having a full and complete Inferior Oolitic fauna. In other words, the Dogger series, the Millepore beds, and the Grey or Scarborough Limestone, are three marine episodes in the greatly developed alternating and Estuarine shales, the upper portion of which is covered by the Cornbrash with a fauna consisting of 71 genera and 145 species, probably the best-developed in England.[2]

[1] Owen, Mono. Mesoz. Mammals (Palæontographical Soc., 1871).

[2] The fauna of the Dogger, Millepore bed, Grey Limestone, and Cornbrash of Yorkshire is as follows:—The Dogger, $\frac{4}{7}\frac{4}{5}$; Millepore bed, $\frac{3}{6}\frac{6}{1}$; Grey Limestone, $\frac{3}{4}\frac{3}{5}$; the Cornbrash, $\frac{7}{1}\frac{1}{4}\frac{1}{5}$; all marine species.

Development.—Proceeding from the Cheltenham area towards Oxford, where the Great Oolite is normally developed, it becomes greatly reduced in thickness. In the Evenlode Valley the four Lower Oolite groups only measure 120 feet at their united maximum thickness.

	Min.		Max.	
Cornbrash	8	to	10	feet.
Forest Marble and clays	20	to	30	„
Great Oolite—white, marly, flaggy . . .	40	to	60	„
	68	to	100	„

Thus, in the region north of Oxford, the true Inferior Oolite is lost, as well as the Fuller's Earth, which in the Stroud Valley is 100 feet thick. The Great Oolite in Oxfordshire differs considerably from the type known at Bath, the difference being due to unequal depth of sea during deposition, involving unequal littoral conditions and estuarine influence.

The Upper Division, or the Bradford Clay and Forest-Marble series, chiefly occurs in Wiltshire. Pale-grey clays cover the Great Oolite beds in the vicinity of Bath, and are fully developed at and near Bradford, where they are best known as the "*Bradford Clay.*" The Forest Marble is so called from the Forest of Wychwood, where it was first observed by William Smith. Taken together in the type localities, they form a variable Zone of separation between the Great Oolite and the overlying Cornbrash, as mapped by the Geological Survey, and as generally understood.

The Bradford Clay is not continuously traceable, but is well developed about Cirencester and Fairford. No "*Apiocrinites*" have yet occurred in any of the Oxfordshire sections, although that is the type fossil in the Bradford Clay of Bradford in Wiltshire.

Estuarine Beds.—In the mass they are marine, but the Forest-Marble beds give strong evidence of accumulation under estuarine condition—fragments of wood, drifted oysters, and here and there *Cyrenæ*, indicate extremely shallow-water deposition or estuarine fluctuations.

The most estuarine and characteristic excavation in the Forest Marble is at Poulton, between Fairford and Cirencester.[1] One of the best sections known occurs also at Kirtlington Station,[2] where nearly 30 feet of Forest Marble are exhibited.

The Great Oolite is extensively quarried or *mined* near Bath, at Box and Corsham; and also on Combe Down, Bath Hampton, and Farleigh Downs. Extensive quarries occur also at Minchinhampton near Stroud (*Hampton Stone*), also at Charlford, Brimscombe, Burley, &c., where the grand fauna collected and described by Messrs. Morris

[1] Worked for roofing-slates, paving-flags, road-metal, &c. The deposit here has no overlie of Cornbrash. The slabs are covered with *Ostræa, Pectens, Limæ*, spines of *Echinoidea*, corals, and wood (Coniferous).

[2] On the Oxford and Birmingham Railway.

and Lycett was obtained.[1] Upwards of 300 species of Mollusca alone have been described from the Minchinhampton Quarries by Mr. Lycett.[2]

The Seven Springs, North Leach, Burford, and Sherborne Park (Gloucestershire), are other fossiliferous localities.

CHAPTER XXXIX.

PALÆONTOLOGY OF THE GREAT OOLITE, FOREST MARBLE, AND CORNBRASH.

General Review.

No less than 239 genera and 836 species are known to occur in or constitute the fauna of the Great Oolite, and no species in six of the classes pass to any higher series, *i.e.*, no species of Mammalia, Reptilia, Pisces, Belemnites, Nautili, or Rhizopoda are known to pass into the succeeding Forest Marble or Cornbrash. Community with the above two subdivisions is chiefly through the *Pelecypoda* or bivalve mollusca and the *Brachiopoda.*

Fauna.—The Great Oolite Limestone of Lincolnshire and the Northern part of Northamptonshire consists of alternate beds of white limestone and marly clay, which contain the following characteristic fossils:—*Ostrea sutrugulosa, O. Sowerbyi, Placunopsis socialis, Homomya gibbosa, Terebratula maxillata, Rhynchonella concinna, Clypeus Mülleri, Isastræa,* and *Cetiosaurian* and *Fish remains.* Few Cephalopoda occur either in Lincolnshire or Northamptonshire.

Of the Cephalopoda six of the seven species are peculiar (see p. 432), *Am. discus* being the only wanderer into the higher members or Cornbrash.

Fish.—Of the 28 species of Fish none occur above, and but for the occurrence of *Strophodus magnus* and *S. tenuis* (which came from the Inferior Oolite below), every species would have been peculiar, or confined to the Great Oolite horizon.

Reptilia.—The chief feature in the Vertebrata are the Reptilian remains, the great Deinosaurs *Megalosaurus*[3] and *Cetiosaurus* not being surpassed in size or detailed perfection in any British formation from which they have been obtained, from the Lias to the Kimmeridge

[1] If the Cornbrash be regarded as Great Oolite, then we have in Yorkshire that formation, which there covers the upper Estuarine shales as a sub-crystalline limestone below the Kellaway series or the Oxfordian group.

[2] Trans. Palæontog. Soc. Mono.:—"Great Oolite Mollusca." 1850–55.

[3] Lately a remarkably fine upper jaw of *Megalosaurus* has been obtained from the Inferior Oolite near Sherborne in Dorsetshire. This is probably the most perfect cranial portion yet found. It was rescued from the Quarry by Mr. Clemenshaw, M.A., of Sherborne, and is now in the museum attached to the Collegiate School of that town.

clay and Portland beds. The Great Oolite of Enslow Bridge, near Oxford, yielded to the researches of Prof. Phillips the remains of the truly gigantic Reptile—*Cetiosaurus*. The Deinosauria are exclusively Mesozoic, ranging from the Trias to the early part of the Cretaceous period, but especially abounding in the Jurassic series.[1]

The number of known Deinosauria is extremely large, commencing in the Trias with *Teratosaurus*, *Amphisaurus*, *Clepsysaurus*, &c. The order underwent great development in the Jurassic and Cretaceous periods. In Britain alone we possess the remains of 8, if not 10, genera, viz., *Iguanodon*, *Hypsilophodon*, *Hylæosaurus*, *Polacanthus*, *Acanthopholis*, *Cetiosaurus*, *Megalosaurus*, *Compsognathus*, &c.[2]

In England the remains of *Megalosaurus* are found from the Lower Lias to the Wealden. In the Cretaceous deposits of North America its place is taken by the representative and allied *Lælaps* (or *Dryptosaurus*.)

Another type of the Deinosauria is the Cretaceous genus *Chondrosteosaurus* (= *Camerosaurus*), also North American. According to Prof. Cope some species of this genus "measured 60 to 70 feet in length, while the massive construction of the skeleton is as remarkable as its linear extension."[3] Associated with *Megalosaurs* in Britain in the Great Oolite are the *Pterosauria* (Huxley), *Ornithosauria* (Seeley). This group is exclusively Mesozoic (Lower Lias to Upper Chalk). *Rhamphorhynchus* and *Pterodactylus* both occur in the Great Oolite (Stonesfield Slate and higher beds).[4]

Palæontology of the Great Oolite in detail.

Plantæ.—Twenty genera and 35 species are distributed through the Great Oolite. The flora of the Inferior Oolite was nearly four

[1] Prof. Huxley places the *Thecodont Reptiles* in this group, thus throwing them back into Middle Triassic times.

[2] The huge *Cetiosaurs* of the Oolitic and Cretaceous deposits are now admitted to be Deinosaurian instead of Crocodilian. The length of the great Oxford species, *C. oxoniensis*, has been estimated by Prof. Phillips to have been at least not under 60 or 70 feet. *Vide* "Geol. of Oxford and Valley of the Thames," pp. 245-294. The *Atlantosaurus* (*Titanosaurus*), however, from the Wealden of Colorado, according to Prof. Marsh, far exceeds *Cetiosaurus* in size, and is as yet the largest terrestrial animal known. Prof. Marsh estimates its length at 50 or 60 feet, and its height to have been at least 30 feet. Its food was the foliage of the mountain forests of the Wealden epoch.

[3] In an American species the "first cervical vertebra is 20 inches in length, and 12 in transverse diameter, and one of the dorsal vertebræ measures 3 feet 6 in. in the spread of its diapophyses; 2 feet 6 in. in elevation, with the centrum 13 inches in diameter."—(Cope.) The femur was 6 feet in length, and the scapula 5 feet 6 inches, while the neck was probably 10 feet long; the vertebræ are opisthocœlous (hollow or concave posteriorly). From the immense size of the scapula and humerus, and the proportionately small size of the pelvis, it may be inferred that these enormous reptiles walked upon all fours. Their habits of existence might have been semi-aquatic.

[4] *Dimorphodon* and *Pterodactylus* occur in the Lower Lias. The species of the Great Oolite series are *Ramphorhynchus Bucklandi*, *R. Prestwichii*, *R. depressirostris*, with *Pterodactylus Aclandi*, *P. Duncani*, and *P. Kiddii*. *Rhamphorhynchus* is confined to the Jurassic rocks.

times as prolific; and, be it remembered, there is not a species in common between the two formations, unless *Thuytes expansus* should prove to be so. *Araucarites Brodiei*, *Aroides Stutterdi*, *Kaidacarpum ooliticum*, and *Stricklandinia acuminata* are amongst the rarer genera occurring; *Palæozamia* and *Thuytes* contain most species; but none of the genera are largely represented. Specifically no two formations, so closely allied through their faunas, could be more distinct through their floras than the Inferior and Great Oolite. No species passes either to the Forest Marble, Cornbrash, or Kellaways Rock, &c., &c.

Protozoa (*Spongida*).—Five genera and 11 species occur in the Great Oolite—*Manon* 1 species, *Scyphia* 2, *Spongia* 4, *Peronella* 3, and *Talpina* 1.

Rhizopoda.—None.

Cœlenterata (*Actinozoa*).—Fifteen genera and 38 species have been described from the Great Oolite; most of these are from the Cotteswolds, although Northamptonshire and Lincolnshire have contributed to the large number of species; none appear in the Kellaways Rock or Oxford Clay (or the Oxfordian rocks). *Cyathophora*, *Isastræa*, and *Thamnastræa* are the only genera largely represented.

Echinodermata.—The whole group in the Great Oolite numbers 22 genera and 53 species. They fall under three sections or groups, the *Echinoidea* (in two sections), the *Asteroidea*, and the *Crinoidea*.

Echinoidea Endocyclica.—Eight genera and 27 species belong to this beautiful group in the Great Oolite—*Acrosalenia* 6 species, *Cidaris* 3, *Hemipedina* 1, *Hemicidaris* 8, *Pedina* 2, *Pseudodiadema* 5, *Rhabdocidaris* 1, *Stomechinus* 1. In the group under consideration, *Acrosalenia hemicidaroides*, *A. spinosa*, *Pedina rotata*, *P. Smithii*, *Polycyphus Normanus*, *Hemicidaris Bravenderi*, and *Pseudodiadema homostigma* pass also to the Cornbrash. Thus of the 27 species, 7 pass to the horizon named.

Exocyclica.—Five genera and 8 species in this singular group of the Echinoidea occur in the Great Oolite. The Great Oolitic genera are—*Clypeus* 2 species, *Echinobrissus* 3, *Galeropygus* 1, *Pygaster* 1, *Pygurus* 1.

Asteroidea.—Only 2 genera (*Astropecten* with 3 species and *Goniaster* with 1) have as yet been detected in the Great Oolite.

The *Comatulidæ* stand alone, and comprise 5 genera, 3 of which with 4 species occur in the Great Oolite—*Actinometra* with 2 species, *Antedon* and *Amphiura* each with one species.

Crinoidea.—*Apiocrinus*, *Bourgueticrinus*, *Millericrinus*, and *Pentacrinus*, in all 10 species, range through the Great Oolite. 36 are known from the whole Jurassic group.

Crustacea.—*Glyphea rostrata*, *Pagurus platycheles*, *Palæinachus longipes*, *Pollicipes ooliticus*, and *Prosopon mammillatum* comprise the whole of the Great Oolite Crustacea. *Glyphea rostrata* is the only species that passes to higher horizons, ranging up to the Coral Rag; the remaining 4 species are restricted.

Polyzoa.—Sixteen genera and 31 species occur through the whole formation. Six of the 31 are common to the Inferior and Great Oolite,

viz., *Diastopora cricopora*, *D. oolitica*, *D. lamellosa*, *D. scobinula*, *Heteropora conifera*, and *H. pustulosa;* and 3 species pass to higher beds, viz., *Berenicea luciensis*, *Stomatopora dichotoma* (to Cornbrash), and *Terebellaria ramosissima* (occurs in the Forest Marble and Coral Rag).

Brachiopoda.—The Great Oolite has yielded 9 genera and 26 species. Numerically *Terebratula* is the richest (7), *Rhynchonella* has 5, *Waldheimia* 4, *Terebratella* 4, and *Crania* 2; 11 species are common to the Great Oolite and Forest Marble, 9 to the Cornbrash, and 4 to the Kellaways.

Pelecypoda (Lamellibranchiata).—Fifty-six genera and about 265 species range through and almost culminate in the Great Oolite; for above this horizon the whole class of the Lamellibranchiata becomes greatly diminished. In the Forest Marble they number 63 species, in the Cornbrash 153, in the Kellaways Rock 85, the Oxford Clay 74, the Corallian beds 151, and the Kimmeridge 100.

Monomyaria.—Sixteen genera and 80 species occur in the Great Oolite; 17 species pass to the Forest Marble, and 33 to the Cornbrash, the upper limit of the Lower Oolite.

Dimyaria.—Forty genera and 185 species occur in this division of the Bivalvia. The chief genera are—*Arca* with 10 species, *Astarte* 21, *Cardium* 10, *Modiola* 14, *Pholadomya* 13, *Tancredia* 9, and *Trigonia* 13. These are the only 7 genera out of the 40 possessing 9 or more species.

Gasteropoda.—Forty genera and 247 species enrich this division of the Lower Jurassic rocks.[1] The Great Oolite fauna of the Minchinhampton beds is not local or exceptional, although so rich, but represents a characteristic series of Mollusca occurring in other and distant localities on the same geological horizon. Out of about 140 species occurring in Oxfordshire, 114 are common to the Minchinhampton beds; this also is confirmed in Somersetshire and Wiltshire. We look to France and the researches of Buvignier for a fauna equal in richness and variety to that of the classical district of Minchinhampton.

Cephalopoda (*Ammonites*).—Seven species occur, and six are peculiar; they are *Am. arbustigerus*, *Am. discus*, *Am. gracilis*, *Am. micromphalus*, *Am. Morrisii*, *Am. subcontractus*, and *Am. Waterhousii;* all but *Am. discus*, which passes to the Cornbrash, are confined to the horizon of the Great Oolite.

Nautili.—*N. Baberi*, *N. dispansus*, and *N. subcontractus* are essentially Great Oolite.

Belemnitæ.—*B. aripistillum*, *B. Bessinus*, and *B. spinatus* are all that are known; the two first are confined to the Great Oolite.

Teuthidæ.—None.

Pisces.—Twenty genera and 58 species occur, and all except two are peculiar. The exceptions are *Strophodus magnus* and *S. tenuis*,

[1] Dr. Lycett in 1863 greatly added to the previously known species, his list embracing, in addition to the Great Oolite fauna, descriptions of the Mollusca of the Stonesfield Slate, Forest Marble, and Cornbrash. In this great work he describes 265 species of Gasteropoda, and from 260 to 265 species of Pelecypoda.

which pass from the Inferior Oolite; so that 56 species commence in and are confined to this horizon. We give the genera and number of species as follows:—

Acrodus	2	species.	
Amblyurus	1	,,	
Asteracanthus	2	,,	
Belonostomus	2	,,	
Caturus	1	,,	
Ceratodus	1	,,	
Ctenolepis	1	,,	
Ganodus	10	,,	
Gyrodus	2	,,	
Hybodus	8	,,	
Lepidotus	2	,,	
Carry forward	32	,,	
Brought forward	32	species.	
Leptacanthus	2	,,	
Nemacanthus	2	,,	
Pholidophorus	2	,,	
Pristacanthus	1	,,	
Pycnodus	12	,,	
Sauropsis	1	,,	
Scaphodus	1	,,	
Sphenonchus	1	,,	
Strophodus	4	,,	
	58	,,	

The genera Hybodus, Pycnodus, and Ganodus are numerically the richest in species. The only known species occurring in the Forest Marble is *Asteracanthus Stutchburii*.

Reptilia.—Thirteen genera and 27 species, both terrestrial and marine, range through the Great Oolite. Some of the most gigantic forms that have inhabited the globe lived during the time when these beds were being deposited; but the position of the land on which these huge terrestrial Dinosaurs lived we have yet to determine. The 13 known genera are—*Testudo, Chelys, Teleosaurus, Streptospondylus, Ichthyosaurus, Plesiosaurus, Pterodactylus, Rhamphorhynchus, Megalosaurus, Cetiosaurus, Cardiodon, Oolithes* (?), *Lacerta*.

Chelonia.—The Chelonia are represented by *Testudo Stricklandi*, Phill., and *Chelys Blakii* from the Stonesfield Slate, the former believed to be a terrestrial species; scutes and a short phalangeal bone are all that are known. The second genus, *Chelys*, occurs in the Stonesfield beds.

Crocodilia.—*Teleosaurus, Streptospondylus*, and *Steneosaurus* all occur in the Jurassic rocks; but only the two former in the Great Oolite. *Streptospondylus Cuvieri* and an unnamed species occur in the Great Oolite or Stonesfield Slate, and the same in the Oxford Clay.

The Crocodilia are divided by Professor Owen into three sub-orders—the *Procœlia, Amphicœlia*, and *Opisthocœlia*. Professor Huxley proposes a more elaborate classification for the Crocodilia: 1. The *Parasuchia*, 2. the *Mesosuchia*, and 3. the *Eusuchia*. Only his second group, the *Mesosuchia*, concerns us here; in it are placed *Streptospondylus* and *Teleosaurus*, both of which occur in the Great Oolite. (*Pelagosaurus, Teleidosaurus, Macrospondylus*, and *Metriorhynchus* are not known as British.) The amphicœlian genus *Teleosaurus* is represented by 3 species—*T. brevidens, T. cadomensis*, and *T. subulidens*, occurring in the Stonesfield Slate and in the higher calcareous divisions of the Great Oolite at Enslow Bridge near Oxford. The extinct amphicœlian Crocodiles are confined entirely to the Mesozoic period. Palæontologically considered, they are the most important group of the order Crocodilia; they are also its most ancient representatives.

The Trias yields the earliest types through *Stagonolepis* and *Belodon*. The home of the amphicœlian Crocodiles is in the Jurassic series, in which the most important genera are *Teleosaurus* and *Streptospondylus*.

Ichthyopterygia (Owen), *Ichthyosauria* (Huxley).—Two species occur, *Ichthyosaurus advena* and *I. erraticus*, in the Stonesfield Slate and beds above. The Ichthyopterygia include only this one genus. The remains are scattered, together with shells, corals, Echinoidea, &c., over the surface of the slates.

Sauropterygia (Owen), *Plesiosauria* (Huxley).—*Plesiosaurus erraticus* is the only species known, and is associated with Ichthyosauria in the Stonesfield Slate. The gigantic Upper Lias forms from near Whitby surpass in size those of any other locality or formation. Although 45 species are known in Britain, only the one species named occurs in the Great Oolite; 5 are found in the Corallian beds, 12 in the Kimmeridge Clay, and 2 in the Portlandian beds. *Pliosaurus* is not known below the Oxford Clay and Corallian rocks.

Pterosauria (*Ornithosauria*, Seeley).—This group of flying Reptilia exclusively belongs to the Mesozoic epoch. The genera *Pterodactylus*, *Dimorphodon*, and *Rhamphorhynchus* all occur in Britain—*Rhamphorhynchus* and *Pterodactylus* in the Great Oolite; the former represented by *R. Bucklandi*, *R. Prestwichii*, and *R. depressirostris*; and the latter by *P. Aclandi*, *P. Duncani*, and *P. Kiddii*.

Deinosauria (*Ornithoscelida*, Huxley).—The whole group is exclusively Mesozoic, ranging from the Triassic to the Cretaceous formations. The most important genera are *Iguanodon*, *Hylæosaurus*, *Megalosaurus*, *Cetiosaurus*, and *Compsognathus*. This order underwent immense development in the Jurassic and Cretaceous periods; and the Cretaceous genera *Hypsilophodon*, *Iguanodon*, *Polacanthus*, *Titanosaurus*, *Acanthopholis*, &c., attest their importance, associated as they are zoologically with *Megalosaurus* and *Cetiosaurus*, which occur in the Jurassic rocks.

Megalosaurus.—This great carnivorous Lizard finds its true home in the Great Oolite.[1] Only one species seems to have been named, but we possess evidence of two others. *Megalosaurus Bucklandi* possibly ranges from the Lower Lias to the Kimmeridge Clay.

Cetiosaurus.—Five species of this wonderful Deinosaur have been described; the grandest form, *C. oxoniensis*,[2] is from the Great Oolite of Enslow Bridge near Oxford. The other species are *C. glymptonensis*, *C. longus* (Owen), and *C. medius* (Owen).

Oolithes.—Are believed to be ova either of Chelonia or Crocodilia. *O. bathonica*, so named by Professor Buckman, is a Great Oolite species.

The following grouping will show the distribution of the Great Oolite Reptilia, and the numerical value of the species:—

[1] *Vide* Phillips, "Geol. of Oxford and Valley of the Thames," pp. 196–219, for the complete history of *Megalosaurus*.

[2] Phillips, *op. cit.*

Chelonia	Testudo	1	species.
	Chelys	1	„
Crocodilia	Teleosaurus	3	„
	Streptospondylus	2	„
Ichthyosauria	Ichthyosaurus	2	„
Plesiosauria	Plesiosaurus	1	„
Pterosauria	Pterodactylus	3	„
	Rhamphorhynchus	3	„
Dinosauria	Megalosaurus	3	„
	Cetiosaurus	5	„
	Cardiodon	1	„
	Oolithes	1	„
	Lacerta	1	„
		27	„

Mammalia.—Four genera with six species have been recognised in the Stonesfield Slate of Stonesfield, namely, *Amphilestes*, *Amphitherium*, *Phascolotherium*, and *Stereognathus*. These were the first-discovered proofs of the existence of warm-blooded quadrupeds in the British strata; since then *Microlestes antiquus* and *Hypsiprymnopsis* (*?*) have been discovered in the Upper Triassic rocks. *Microlestes* finds its nearest ally amongst existing mammals in the marsupial and insectiverous *Myrmecobius*, or Banded Ant-eater, of Australia; teeth only of *Microlestes* have as yet occurred. The Marsupialia fall under two primary groups, the *Diprotodontia* and *Polyprotodontia*. The living Diprotodonts embrace the herbivorous *Macropodidæ*, *Phascolomys*, *Hypsiprymnus*, and the *Phalangistidæ*. The Polyprotodonts, *Perameles*, *Didelphidæ*, *Myrmecobius*, *Dasyurus*, and *Thylacinus* are carnivorous. Both these habits may also be ascribed to the fossil forms, the characters of the teeth, in the fossil as well as in the living, being conclusive evidence.

Amphitherium, from the Stonesfield Slate, is related to the living *Myrmecobius*. *Amphilestes* and *Phascolotherium* were also insectivorous Marsupials, *Phascolotherium* finding its nearest living ally in the American Opossums. *Stereognathus* stands in a dubious position; possibly it may be "placental."

The association of the Marsupialia then, as now, with a peculiar land flora (Araucariæ and Cycadeæ), and the presence in the Jurassic seas of the Cestraciontidæ and the Molluscan genus *Trigonia* (now exclusively confined to the Australian seas), tend to show that in England, at the time of the deposition of the Great Oolite or the Stonesfield Slate, there must have been both a fauna and a flora resembling in a remarkable manner those now occurring in Australia.

TABLE LXIII.—*Analysis and Distribution of the Great Oolite Species.*

From Fuller's Earth.	Classes.		Genera.	Species.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Corallian Beds.	Kimmeridge Clay.	Portland Oolite.
		Plantæ	20	35							
		Amorphozoa . .	4	9	...	...	...	...	1/4		
		Rhizopoda (none)									
		Cœlenterata . . .	15	38	1/4	4/5					
1/22		Echinodermata . .	22	53	4/11	1/10					
1/4		Annelida	2	7	1/4	1/4	1/4	1/4	1/4		
		Crustacea . . .	5	5	...	1/4	1/4	...	1/4		
1/3		Bryozoa	16	31	1/4	1/4	...	...	1/4		
1/4		Brachiopoda . .	9	26	1/11	2/9	2/3	1/4			
1/17	56 genera and	Monomyaria . .	16	80	2/17	13/41	3/4	3/4	2/3	2/3	
10/16	265 species.	Dimyaria	40	185	10/16	20/41	1/4	1/4	10/16		
1/4		Gasteropoda . . .	40	247	10/11	8/17	2/3	2/3	1/4		
1/4		Ammonites . . .	1	7	...	1/4					
	Cephalopoda.	Nautili	1	3							
1/4		Belemnites . . .	1	3							
		Teuthidæ (none)									
1/3		Pisces	20	58							
		Reptilia	13	27							
		Mammalia . . .	4	6							
40/57		.....	229	820	42/44	60/170	11/16	7/15	17/19	2/3	

Palæontology of the Forest Marble.

Plantæ.—None, or only fragments of wood.

Protozoa.—None.

Cœlenterata.—The only species known in the Forest Marble is *Anabacia orbulites*, and the same passes up to the Cornbrash.

Echinodermata.—Six genera and 10 species occur, 6 of which had previously appeared in the Inferior and Great Oolites; these connecting species are *Acrosalenia pustulata*, *A. spinosa*, *Apiocrinus Parkinsoni*, *Cidaris bradfordiensis*, *Clypeus Mülleri*, and *C. Plottii*. The remaining 4 are strictly Forest Marble species, and are *Apiocrinus elegans*, *Astropecten Huxleyi*, *A. Phillipsii*, and *Hemicidaris alpina*. *Acrosalenia spinosa* passes to the Cornbrash; we know of no other common to the two horizons.

Annelida.—*Serpula intestinalis* is the only species occurring in the Forest Marble, and this form has the longest continuous range of any in the Jurassic rocks. It has been found in 6 horizons, viz., from the Great Oolite to the Coral Rag inclusive.

Crustacea.—None.

Polyzoa.—*Spiropora straminea* and *Terebellaria ramosissima* are the only two species occurring in the Forest Marble.

Brachiopoda.—*Terebratula, Waldheimia,* and *Rhynchonella* are the Forest Marble genera, and they include 10 species, viz., *Terebratula* 4, *Waldheimia* 3, and *Rhynchonella* 3. Eight of the 10 species are also common to the Cornbrash.

Pelecypoda (Lamellibranchiata). *Monomyaria.*—Nine genera and 24 species occur. The poverty of species in certain groups, and total want of representation of many whole classes in the Forest Marble, is readily accounted for through the nature of the deposit and the mode of its accumulation; for, as we shall see, no *Nautili*, no *Pisces*, no *Reptilia*, and no *Mammalia* have yet occurred with all the research that this group has undergone.

Dimyaria.—Nineteen genera and 39 species have been obtained from the Forest Marble; 16 species are also in the horizons below, and 19 pass to the Cornbrash. The two chief genera are *Astarte* and *Trigonia*. The former possesses 8 species, and the latter 6. This paucity is striking, but in conformity with the physical conditions that prevailed. *Pholadomya, Myacites, Modiola, Lucina, Goniomya, Arca, Cardium, Ceromya,* and *Cyprina*, all moderately deep-sea forms, are almost totally unrepresented, yet the succeeding Cornbrash has yielded 33 genera and 98 species.

Gasteropoda.—Nineteen genera and 43 species have been recorded from this horizon, mostly from the counties of Gloucester, Somerset, and Dorset. Sixteen genera and 31 species pass from the Great Oolite and unite the two subformations; but only 2 species, *Patella cingulata* and *Actæonina Luidii*, pass to the succeeding Cornbrash; none to the Kellaways Rock. Forty-one species of the Gasteropoda, therefore, do not range beyond the Forest Marble; overlapping forms from the Great Oolite to the Cornbrash, and not appearing in the Forest Marble, number 9 genera and 14 species.

Cephalopoda. *Ammonites.*—*Ammonites Herveyi* is the only species really known in the Forest Marble, and this form also occurs in the Cornbrash.

Nautili.—None known.

Belemnites.—None known.

Pisces.—*Asteracanthus Stutchburii.*

Reptilia.—*Bothriospondylus robustus* and remains of *Streptospondylus* belonging to the Crocodilia, and the Deinosaur *Megalosaurus Bucklandi*, comprise all we know of the Reptilia in the Forest Marble.

Mammalia.—None known.

Range and Palæontology of the Cornbrash.

From Dorsetshire to Yorkshire this thin but important division of the Lower Oolites is scarcely lost; it forms the uppermost subdivision of the Great Oolite, and terminates systematically and naturally the Lower division of the Jurassic rocks.

Lower Jurassic.	Kellaways Rock.	
	Cornbrash.	Great Oolite Group.
	Forest Marble.	
	Great Oolite (Upper).	
	„ (Lower).	
	Stonesfield Slate.	
	Fuller's Earth.	Inferior Oolite Group.
	Inferior Oolite.	

The Cornbrash rarely exceeds 8 feet in thickness, but always marks the upper limit of the Bath or Great Oolite series, its continuity being more marked and persistent than that of any of the minor divisions of the Lower Oolites.

Fauna.—Careful analysis of the species occurring in the Cornbrash proper, shows that the fauna represents 92 genera and 244 species; 42 genera and 120 species (or 50 per cent.) pass up from the Great Oolite; and 30 genera and 56 species pass from the Cornbrash to the succeeding Kellaways Rock. Those classes possessing the greatest number of representative species are the Brachiopoda, 19; the Pelecypoda (*Monomyaria*), 55; (*Dimyaria*), 98; Gasteropoda, 28; and the Echinodermata, 23. The Cephalopoda are scarcely represented, *Ammonites discus*, *A. Herveyi*, and *A. macrocephalus* being all the known species associated with *Nautilus hexagonus*; only one species of Belemnite (*B. tornatilis*) has yet appeared in the Cornbrash.

The Cornbrash of Northamptonshire,[1] Huntingdonshire,[2] Lincolnshire,[3] Yorkshire,[4] and Oxfordshire [5] yields so similar a fauna along its strike through England as to be zoologically significant, as well as clearly defined stratigraphically. Whether the Cornbrash of Yorkshire is upon the same geological horizon as that of Lincolnshire and Mid-England is doubtful. In Yorkshire its physical development is very different from that of any area south of the Humber, the Rushden and Stilton beds being lithologically totally unlike the northern type.

Characteristic Species.—Certain species are highly characteristic of the formation both vertically and horizontally. The following are important forms:—*Acrosalenia spinosa* and *A. Hemicidaroides*, *Holectypus depressus*, *Echinobrissus quadratus*, *Myacites securiformis*, *Ceromya concentrica*, *Cardium dissimile*, *Trigonia elongata*, *Avicula echinata*, *Ostrea flabelloides*, *Pecten arcuatus*, *Terebratula intermedia*, *T. Bentleyi*, *T. obovata*, *T. coarctata*, *Ammonites macrocephalus*. These species occur everywhere throughout England where the Cornbrash is developed.

Palæontology.—Although the Cornbrash makes no physical or stratigraphical feature in Yorkshire, yet palæontologically it is of much importance. Leckenby, Lycett, Huddleston, and others have written its history through the fossils collected. It physically marks the termination of the Upper Estuarine series of the Lower Oolite, constituting, with the Dogger, Grey Limestone, and Millepore-bed, four marine episodes in the greatly developed Estuarine group of Yorkshire.

[1] Oundle, $\frac{1}{14}$; Peterborough, $\frac{1}{11}$; Rushden, $\frac{1}{14}$; Manthorp, $\frac{1}{15}$.
[2] Stilton, $\frac{1}{10}$. [3] Bourne, $\frac{1}{13}$. [4] $\frac{70}{135}$. [5] $\frac{44}{71}$.

This uppermost horizon of the Lower Oolite is rich only in the Echinodermata, Pelecypoda, and Gasteropoda.

Coelenterata.—*Anabacia orbulites*, the only known species, ranges from the Inferior Oolite direct to the Cornbrash.

Echinodermata.—Twelve genera and 23 species may be said to range through England, the persistency of the Cornbrash from Dorsetshire to Yorkshire being, as we have said, continuous, although it is never many feet in thickness. The 12 genera are sparingly represented. With the exception of the Asteroid *Ophiurella Griesbachii*, the whole of the class belong to the Echinoidea. Four genera—*Echinobrissus* 3 species, *Holectypus* 1, *Pygaster* 2, *Pygurus* 1—represent the group Exocyclica or "irregulares;" and *Acrosalenia* 4 species, *Hemicidaris* 1, *Hemipedina* 2, *Pedina* 2, *Polycyphus* 1, *Pseudodiadema* 4, and *Stomechinus* 1 species, belong to the Endocyclica or "regulares."

Annelida.—The Tubicola, through the genus *Serpula*, with 5 species, include all the known Annelida; but only 1 is truly Cornbrash, viz., *S. quadrata*. *S. vertebralis* occurs in the Oxford Clay also; and *S. intestinalis* ranges from the Great Oolite to the Coral Rag inclusive.

Crustacea.—*Glyphea Birdii*, *G. rostrata*, and *G. scabrosa* are the only 3 Crustacea known in the Cornbrash. *G. scabrosa* is a Yorkshire form.

Polyzoa.—*Berenicea diluviana*, *B. luciensis*, *Hippothoa Smithii*, *Spiropora straminea*, and *Stomatopora dichotoma* are the 4 genera and 5 species that occur in the Cornbrash. *Hippothoa Smithii* belongs only to this horizon. The other 4 named species reach the Cornbrash from lower beds.

Brachiopoda.—*Terebratula* with 5 species, *Waldheimia* with 8, *Rhynchonella* with 5, and *Discina* with 1, comprise all that are known in the Cornbrash. *Waldheimia obovata*, *W. ornithocephala*, *Terebratula coarctata*, *T. intermedia*, and *T. obovata* pass to the Kellaways Rock.

Pelecypoda (Lamellibranchiata). *Monomyaria.*—Eleven genera and 55 species occur, chiefly belonging to the genera *Avicula* (6 species), *Gervillia* (5), *Lima* (8), *Ostrea* (8), and *Pecten* (16); the remaining 6 genera number but few forms. The 7 genera and 14 species that pass direct to the Kellaways Rock are *Avicula braamburiensis*, *Gervillia aviculoides*, *Lima duplicata*, *L. pectiniformis*, *Ostrea flabelloides*, *O. Sowerbyi*, *Pecten annulatus*, *P. armatus*, *P. demissus*, *P. fibrosus*, *P. inæquicostatus*, *P. lens*, *P. vagans*, *Perna rugosa*, and *Placunopsis inæqualis*. The restricted species, so far as we know, are *Hinnites gradus*, *H. gradatus*, *Lima helvetica*, *L. rigidula*, *Ostrea spatiosa*, *Pecten anisopleurus*, *P. cingulatus*, and *P. rushdenensis*. Nine species pass to the Oxford Clay (*Gervillia aviculoides*, *Lima duplicata*, *L. pectiniformis*, *Pecten annulatus*, *P. arenatus*, *P. demissus*, *P. fibrosus*, *P. lens*, and *P. vagans*).

Dimyaria.—Thirty-three genera and 98 species range through England. *Pholadomya* and *Trigonia* are the only two largely represented genera, the former by 10, the latter by 13 species. The Cornbrash

receives from the Forest Marble 11 genera and 19 species; and 12 genera and 27 species pass to the succeeding Kellaways Rock. Eight genera and 16 species first appear in it. Those strictly confined to the Cornbrash, so far as we at present know, are—*Astarte Leckenbyi, Cardium latum, Leda rostralis, L. variabilis, Lucina Beanii, Myacites uniformis, Opis Leckenbyi, O. scarburgensis, Sanguinolaria parvula, Trigonia cassiope, T. scarburgensis,* and *T. tripartita.*

Gasteropoda.—Twenty genera and only 28 species have as yet been described from the Cornbrash. Nine genera and 11 species are entirely confined to it. They are—*Actæonina scarburgensis, Amberlya armigera, Ceritella costata, Nerinæa granulata, Nerita granulata, Neritopsis d'Archiaci, N. Guerrei, Purpuroidea ornata, Trochus strigosus, Chemnitzia vetusta,* and *C. vittata.* Only 2 species connect the Forest Marble and Cornbrash, viz., *Actæonina marginata* and *Patella cingulata.* Six species pass to the succeeding Kellaways Rock in Yorkshire, viz., *Pleurotomaria granulata, Natica* (or *Littorina*) *punctata, Amberlya ornata, Dentalium entaloideum, Alaria trifida,* and *A. bispinosa.*

Cephalopoda (*Ammonites*).—*Ammonites discus, A. Herveyi,* and *A. macrocephalus* constitute the Ammonitidæ. *A. macrocephalus* ranges into the Kellaways Rock and Oxford Clay.

Nautili.—*Nautilus hexagonus* is the only species; it occurs also in the Kellaways Rock and Corallian beds.

Belemnites.—No Dibranchiata known.

Pisces.—*Asteracanthus acutus* and *Isodius leptognathus* constitute all the known Cornbrash fishes.

Reptilia.—Remains of *Megalosaurus Bucklandi.*

Mammalia.—None known.

Avicula Echinata Shales.

These are a series of shaly beds above the Cornbrash Limestone, and the abundance of *Avicula echinata* occurring in them would at first ally them with the Cornbrash. The marked physical or lithological line, however, below is so constant and definite that these shales should be taken as forming the base of the Kellaways Rock. "They anticipate to a certain degree the physical conditions of the Oxford Clay, interrupted for a time by the great arenaceous Kellaways series which intervenes." These shales are uniform in character, and are from 10 to 15 feet thick.[1] Mr. Huddleston gives the following section, showing them from Cunstone Nab, Gristhorpe Bay :—

	Feet.	In.
Drift, Calcareous Grit, and Oxford Clay (about) .	210	0
Kellaways Rock, fossiliferous, top-bed wanting . .	4	8
Blue shales } *Avicula echinata* shales . . {	9	0
Rotten shales } {	1	0
Impure ferruginous Limestone (Cornbrash) . .	1	0
Clays, &c., of the upper shale and sandstone (about) .	45	0
	270	8

[1] In the Hambleton Escarpment, Prof. Phillips mentions argillaceous beds at the base of the Kellaways Rock. Q. Jour. Geol. Soc. vol. xiv.

"In N.W. Germany, where a line of Jurassic rocks stretches over a meridian of 160 miles, from the Elbe to the Ems, these Yorkshire beds may be represented by the 'sandy shales' containing *Avicula sulcata*. These '*Avicula shales*' of Germany are from 20 to 25 feet thick at the Porta Westphalica, and as we find them on the Yorkshire coast they are not sharply divided from the *Ammonites macrocephalus* beds."[1]

Fauna.—About 20 species have been collected from these shales, and the fauna on the whole is that of the Cornbrash. Except the Macruran crustacean *Glyphæa Stricklandi*[2] all are Bivalve Mollusca (13). *Pecten lens, P. demissus, Lima rigidula, Avicula sulcata, Modiola cuneata, Gresslya peregrina,* and *Goniomya literata,* &c., are the chief forms.

CHAPTER XL.

MIDDLE JURASSIC STRATA:—KELLAWAYS ROCK, OXFORD CLAY, AND LOWER CALCAREOUS GRIT.

THE Middle Jurassic rocks comprise two complete and distinct groups—

1. The Oxfordian;
2. The Corallian.

I. **Oxfordian.**—divisible into two sections, *a* and *b*, the Kellaways Rock and the Oxford Clay.

Section *a*.—KELLAWAYS ROCK.[3]

Lower Zone of Calcareous Sandstone (Callovian).—This is an important subdivision of the Middle Oolites, both on the Yorkshire coast and in the interior of the country, as well as on the site where first described at Kellaways in Wiltshire.

In Yorkshire it attains important thickness, with a fauna numbering 52 genera and 168 species; 31 genera and 56 species pass up from the Cornbrash, and 60 species pass to the Oxford Clay. The Kellaways Rock is finely exhibited at and near Scarborough, where it is about 80 feet thick, and lies immediately above the dark shales of the Cornbrash. It contains the same fossils as those of Kellaways Bridge in Wiltshire. Westwards from Scarborough, the rock may be traced as a thick zone of indurated sandstone across

[1] "Von Seebach appears *here* to draw the line between the Middle and Upper Jura, whilst Dr. Brauns extends that line to the top of the Ornatenthone, which have their equivalents in the very highest part of the Kellaways Rock of Scarborough."

[2] It is from the pale buff phosphatic nodules in these shales (rather than from the Cornbrash) that these crustacea are derived.

[3] The Kellaways Rock has been described in detail by Leckenby, Q. J. Geol. Soc., vol. xv. p. 4; and Huddleston, Proc. Geol. Assoc., vol. iv.

the county, where it occupies the base of the great escarpment which terminates the tabular range towards the north. In Newtondale it is conspicuous below and conformable to the Lower Calcareous Grit; it also constitutes the base of Roulston scar, overlooking the great central plain of Yorkshire. The Kellaways Rock is by no means constant in thickness along the coast from Scarborough towards the south-east; it is last seen at Newbiggin Wyke, at the base of the cliffs in Gristhorpe Bay, where it is little more than 5 feet, having been reduced from 80 feet at Scarborough to that thickness at Gristhorpe Bay. It is observable at Wheatcroft, Red Cliff, and all along the Gristhorpe Cliff to Newbiggin; at North Cliff (Scarborough) it is 80 feet thick, occurring in 5 well-defined beds or subdivisions. The following section is given by Mr. W. H. Huddleston from the North Cliff:—[1]

	Ft.	In.
Broken rock. Very ferruginous; hard when not exposed. Contains *Belemnites Owenii, Ostrea labelloides, Gryphæa dilatata,* and *Ammonites of the group Ornati*	4	0
Upper tier of solid stone. Contains a band of sub-crystalline fossiliferous rock, from which most of the ammonites and other shells marked Kellaways Rock have been obtained, 1 foot; rotten irony sandstone, with similar fossils, 1 foot 6 in.; building-stone poor in fossils, 7 feet 6 in.[2]	10	0
Loose muddy sandstones (thickness estimated)	20	0
Lower tier of solid stone. Contains a hard bed charged with *Belemnites Owenii*	12	0
Loose clayey sandstones. Contain hard bands and doggers, with *Astarte* like *A. carinata,* Phil., *Trigonia Rupellensis, Modiola cuneata, Avicula Braamburiensis, Pholadomya Murchisoni,* &c. .	30	0
	76	0

Wiltshire.—The Kellaways Rock in Wiltshire occurs in lenticular masses, 8 to 10 feet thick, containing numerous casts of Ammonites and other mollusca. In Bedfordshire, Northamptonshire, and Lincolnshire the sandy beds with characteristic fossils occur at the base of the Oxford Clay; they bear all the evidence of being the connecting link between the shallow-water Cornbrash and the deep-sea Oxford Clay, and contain many of the species found in each of these formations, with others peculiar to the Kellaways.

Fauna.—"The fauna is rather estuarine, indicating a partial renewal of the physical conditions which had produced the three great Estuarine Series below the Cornbrash." The fine section shown under High Red Cliff, south-east of Wheatcroft, supports the dark-grey shales of the Oxford Clay, which again are surmounted by the Calcareous Grit. The Kellaway here may be divided into two groups—an upper and truly marine, with numerous Ammonites, and a lower, less marine in character. The Kellaways Rock contains a remarkable assemblage of fossils.[3] The most abundant Ammonites are *A. Goweri-*

[1] Proceed. Geol. Assoc., vol. iv. p. 363–64, 1876.

[2] Most of the fossils in the Kellaways Rock at Scarborough and elsewhere in Yorkshire occur in the upper 6 feet.

[3] See Leckenby. Q. Jour. Geol. Soc., vol. xv. p. 6.

anus, A. calloviensis, A. Kœnigi, A. modiolaris, A. macrocephalus, and *A. Chamuseti.* None of the group Ornati occur here. *Belemnites Owenii, Astropecten arenicolus, A. orion, Gryphæa bilobata, Lima notata,* &c., eminently distinguish this group. In the interior of the county, in Newtondale, north-west of Hackness and the Goothland region, and near North Cave, the Kellaway series are finely developed.[1] In Lincolnshire the Kellaways Rock has become attenuated to a thickness of not more than 3 feet, but everywhere containing the characteristic shell, *Gryphæa bilobata.*

The Yorkshire and Wiltshire series have yielded 52 genera and 168 species. Many Cornbrash species pass up into the Kellaways Rock, no less than 31 of the 52 genera, and 56 of the 168 species uniting them. It is through the Cephalopoda (Ammonites) that the Kellaway or Oxfordian group is so distinguished, and this chiefly through the Yorkshire deposits. The upper or Cephalopoda division seems to contain Ammonites belonging to two geological divisions, of which *Am. modiolaris* and *Am. Gowerianus* represent Callovian forms; whilst *Am. Duncani, Am. Jason* (Reinecke), *Am. Lamberti,* &c., are characteristic of the Lower Oxfordian or Ornatus Clays. At Scarborough the group *Ornati* is abundant; at Red Cliff *Am. Gowerianus;* at Gristhorpe the *Cordati* predominate, through *A. Vertumnus* and *flexicostatus.*

The fauna of the *upper part* of the Yorkshire Kellaway series, as indicated by its Ammonites, embraces much of the Oxfordian of English geologists.[2] The characteristic species are—CEPHALOPODA, *Belemnites Owenii,* and *B. hastatus, Nautilus hexagonus, Ammonites Gowerianus, A. Kœnigi, A. Athleta, A. Jason, A. Duncani, A. Chamuseti,* and *A. modiolaris.* GASTEROPODA, *Alaria bispinosa, Pleurotomaria granulata,* and *Cerithium Culleni.* PELECYPODA, *Gryphæa dilatata, G. bilobata, Pecten fibrosus, Avicula Braamburiensis, Modiola cuneata, Trigonia paucicosta, Cardium cognatum, Goniomya literata, Myacites calceiformis.* BRACHIOPODA, *Waldheimia ornithocephala* and *Rhynchonella socialis.*[3]

Prominent in the fauna are the Ammonites, 40 species of which make their appearance in the Kellaways Rock of this area, whereas only 1 species (*A. macrocephalus*) is known in the underlying Cornbrash. The Ornati present two well-marked divisions. *A. Gulielmi,* Sow., is the type of one division. The second is characterised by *Am. Duncani* and a variety, *A. gemmatus,* Phill. The next great group is the Cordati (Amalthei), which are abundant at Gristhorpe Bay, and the same forms are numerous in the bottom bed of the Oxford Clay of Scarborough Castle Hill. The family of the Trigoniæ are important witnesses in the Kellaways Rock, and each species seems to occupy its own particular bed.

[1] Huddleston, *loc. cit.,* p. 369–70. After leaving the neighbourhood of Brigg, in Lincolnshire, the Kellaways Rock is not again met with until reaching its original area in Wiltshire.

[2] The best localities for Kellaways Rock fossils on the Yorkshire Coast are Scarborough, Red Cliff, and Gristhorpe.

[3] Besides the above-named species, there are others which essentially distinguish the Kellaway from the Cornbrash or Oxford Clay. These are *Solemya Woodwardiana, Trigonia complanata, Cardium sub-dissimile,* and *Anatina versicostata.* Nowhere in Britain are the Oxford Clay and Kellaways Rock so finely exposed as at Scarborough and its neighbourhood, where the latter attains to 80 feet.

Section *b*.—The Oxford Clay.

Thickness and Range.—This great argillaceous deposit ranges all through England, from the Dorsetshire coast to the district of Scarborough, where it consists of dark-grey, slate-coloured, and brown clay and bituminous shale, the thickness varying from 300 to 600 feet. From the nature of its materials and the conditions of its deposit or sedimentation, it is deficient in certain forms of life which were probably abundant in neighbouring areas of clear water. No corals or Protozoa are known in the Oxford Clay of Britain, and only 3 species of Echinodermata (given in the analysis) occur. The upper portion of the Oxford Clay is chiefly fossiliferous. It ranges through England from Weymouth to Yorkshire, more or less without intermission or interruption. From Weymouth across the vale of Blackmore by Chippenham (Wilts), through Oxfordshire into Huntingdonshire, it forms the substratum of the western part of the Fen land, and occurs near Wellingborough, Hackness, and Scarborough.

In Yorkshire the Oxford Clay does not exceed 170 feet, and rests upon the hard, irony, and fossiliferous Kellaways. On the coast it is first seen at Scarborough, is thin like its base (the Kellaways Rock), and only partially seen until reaching Cayton Bay; it thence constitutes the bulk of the cliff (capped by the Lower Calcareous Grit) to within a short distance of Filey Brigg.

Fauna.—The fauna of the Oxford Clay is rich in Bivalve Mollusca (Pelecypoda) and Cephalopoda—both Ammonites and Belemnites. Numerically the fauna comprises 74 genera and 195 species—Plantæ 1 species, Rhizopoda 3, Echinodermata 3, Annelida 2, Crustacea 6, Brachiopoda 10, Pelecypoda (Monomyaria) 26, Dimyaria 48, Gasteropoda 17, Ammonites 45, Ancyloceras 1, Belemnites 13, Teuthidæ 2, Pisces 4, and Reptilia 13 species (see detailed analysis). The Oxford Clay is well developed at Ampleforth, "in the valley which communicates with the central plain of Yorkshire by the gap at Coxwold." This valley has been chiefly excavated out of the Oxford Clay, which here attains considerable dimensions. Most of the fossils occurring at Scarborough, &c., are found a few feet only above the Kellaways Rock. Some of the more characteristic species are *Belemnites hastatus*, *B. Owenii*, *Ammonites Lamberti*, *A. cordatus*, *A. vertebralis*, *A. Mariæ*, and *A. crenatus*, *Gryphæa dilatata*, *Pecten vagans*, *Avicula inæquivalvis*, *Modiola bipartita*, *Astarte carinata*, *Pholadomya simplex*, and *Rhynchonella socialis*. The following numerical statement shows the value of the fauna in the Oxford Clay of Yorkshire:—

Cephalopoda—*Belemnites* 3 species, *Ammonites* 11; Gasteropoda 4; Pelecypoda—*Monomyaria* 10, *Dimyaria* 13; Brachiopoda, 2 species—in all, 43 species.

For the purposes of comparison with N. Germany, negative evidence shows that the group "Ornati" does not occur higher than the top of the Kellaways Rock, and we must regard this great thickness of beds as belonging quite as much to the Upper as the Middle Jura of that country.

The table on page 445 shows the geographical distribution of the Jurassic horizon through four typical areas.

TABLE LXIV.—*Showing the Geographical Distribution of the Jurassic Horizons through Four Typical Areas.*

	Geological Horizons.	Cotteswold Hills.	North-east Oxfordshire and South Northamptonshire.	North Northamptonshire and South Lincolnshire.	South Yorkshire.
Middle Jurassic.	Oxfordian	Oxford Clay with Kellaways Rock at its base	Oxford Clay	Oxford Clay, with Sandy beds representing Kellaways Rock at its base.	Sands strata with Oxfordian fauna.
Lower Jurassic. Great Oolite	Cornbrash	Cornbrash	Cornbrash	Cornbrash.	absent.
Great Oolite	Great Oolite, Upper zone	Forest Marble and Bradford Clay. Great Oolite Limestone	absent. Great Oolite Limestone	Thin argillaceous beds. Great Oolite Clays. Great Oolite Limestone.	absent.
Great Oolite	Great Oolite, Lower zone	Great Oolite Limestone with Stonesfield Slate	Upper part of the Northampton Sand.	Upper Estuarine series.	absent.
Transition series.	Fuller's earth	Upper and Lower Fuller's Earth with the Fuller's Earth rock.	absent.	absent.	absent.
Lower Jurassic	Zone of *Ammo. Parkinsoni*	The Ragstone of the Inferior Oolite, including the Trigonia Grit, the Gryphite Grit, the Pholadomya Grit, and the Chemnitzia Grit.	absent.	absent.	absent.
Lower Jurassic	Zone of *Am. Humphresianus*	The Upper Freestone.	absent.	absent.	absent.
Lower Jurassic	Zone of *Am. Sowerbyi*	The Oolite Marl.	absent.	The Lincolnshire Oolite	Sands and Limestones of Cave, &c.
Lower Jurassic	Zone of *Am. Murchisonæ*	The Lower Freestones of the Pea-grit.	Lower portions of the Northampton Sand	The Northampton Sands	
Transition series.	Midford Sand	Cephalopoda-beds and Sands.			
Lias	Zone of *Am. communis*	Upper Lias Clay	Upper Lias Clay	Upper Lias Clay	Upper Lias Clay.

Palæontology of the Kellaways Rock.

Plants
Protozoa } None known.
Cœlenterata

Echinodermata.—Only 3 species occur. They are *Astropecten arenicolus*, *A. clavæformis*, and *A. orion*. No Echinoidea or Crinoidea known.

Annelida.—*Serpula intestinalis* stands alone out of the 35 species that occur in the Jurassic rocks. This same species also occurs in the Oxford Clay and Corallian beds.

Crustacea.—*Glyphea rostrata* and *G. Stricklandi*; the former first appeared in the Inferior Oolite.

Polyzoa.—None.

Brachiopoda.—*Terebratula coarctata*, *T. intermedia*, *T. obovata*, *Waldheimia ornithocephala*, *W. umbonella*, *Rynchonella varians*, *R. socialis*, *R. yaxleyensis*, *Lingula lævis*, *Discina centralis* comprise all the species in the Kellaways Rock. *R. varians* and *Wald. ornithocephala* also occur in the Oxford Clay.

Pelecypoda (Lamellibranchiata) *Monomyaria.*—Eleven genera and 28 species occur, 14 of which passed from the Cornbrash. The species that commence or first appear in the Kellaways Rock are *Anomia inæquivalvis*, *Avicula ovalis*, *Exogra nana*, *Gryphæa bilobata*, *G. dilatata*, *Lima notata*, *L. obscura*, *Ostrea archetypa*, *O. procerula*, *O. striata*, *O. undosa*, and *Pinna mitis*; but only 4 genera and 8 of the above species are essentially Callovian, viz., *Anomia inæquivalvis*, *Gryphæa bilobata*, *Lima notata*, *L. obscura*, *Ostrea archetypa*, *O. procerula*, *O. striata*, and *O. undosa*.

Dimyaria.—Eighteen genera and 57 species constitute the Dimyarian fauna of the Kellaways Rock; 27 species are also Cornbrash forms, 13 pass up to the Oxford Clay, and 14 to the Corallian beds. The special Callovian forms are *Anatina versicostata*, *Cardium subdissimile*, *Corbis lævis*, *Cucullœa æmula*, *C. minima*, *Isocardia clarissima*, *Lucina lirata*, *L. pulchra*, *Modiola Morrisii*, *Myacites Alduini*, *Nucula ornata*, *Solemya Woodwardiana*, *Trigonia complanata*, *T. paucicostata*, *T. rupellensis*, and *T. Williamsoni*. These all commence in and are confined to the Kellaways, none ranging higher. It will be seen that 9 of these genera are only represented by 1 species each. If the same occurred in living genera, we should regard them as extremely rare; and there are examples in our modern seas of the same rarity (e.g., *Pholadomya*). It is only negative evidence withal that we possess when dealing with the paucity or abundance of species in any given formation.

Gasteropoda.—Very few of the genera and species of the Kellaways Gasteropoda range higher. The fauna, too, is small, only 19 species. Those specially restricted are *Alaria arsinoe*, *Cerithium abbreviatum*, *C. crebrum* (?), *Chemnitzia lineata*, *Patella graphica*, *Pleurotomaria arenosa*, *P. guttata*, and *P. striata*. None of these occur out of the Kellaways Rock; and most of them are Yorkshire forms. Four species first appear in the Kellaways, viz., *Pleurotomaria depressa*,

Alaria armigera, *Actæon retusus*, and *Dentalium annulatum*. Thus the 12 species must be considered as constituting the typical Gasteropoda of the formation. Only 5 genera and 6 species unite the Lower and Middle Oolites. They are:—*Alaria bispinosa*, *A. trifida*, *Dentalium entaloideum*, *Amberlya ornata*, *Natica punctura*, and *Pleurotomaria granulata*.

Cephalopoda.—*Ammonites*.—No less than 41 species of Ammonites suddenly appear in the Callovian beds. Thirty-three of these occur in the Yorkshire deposits. Our knowledge of these is largely due to the researches of Phillips and Leckenby.[1] Twenty of the 41 species pass to the Oxford Clay and 4 to the Corallian beds. The 17 species actually confined to the Kellaways group are *Amm. alternans*, *Amm. auritulus*, *Amm. Bakeriæ*, *Amm. Baugieri*, *Amm. convolutus*, *Amm. Eugenii*, *Amm. flexicostatus*, *Amm. fluctuosus*, *Amm. goliathus*, *Amm. Henrici*, *Amm. Lalandianus*, *Amm. Lonsdalei*, *Amm. oculatus*, *Amm. planula*, *Amm. tatricus*, *Amm. varicostatus*, *Amm. Vernoni*. Only 1 species (*Amm. macrocephalus*) passes from the Cornbrash to the Kellaways. The 4 species that pass to the Corallian beds are *Amm. alligatus*, *Amm. Gulielmi*, *Amm. perarmatus*, and *Amm. placenta*. They range no higher. Scarborough, Redcliff, Hackness, and Gristhorpe are the chief localities from which the Kellaways Ammonites have been obtained.

Ancyloceras.—Only 2 Jurassic species are known—*A. annulatum*, in the Inferior Oolite, and *A. calloviense*, from the Kellaways Rock of Wiltshire.

Nautili.—*Nautilus calloviensis* and *N. hexagonus* comprise all the known species.

Belemnitidæ.—The Dibranchiata are equally poor. We known only *Belemnites Owenii*, *B. hastatus*, and *B. tornatilis*.

Pisces.—Teeth of *Strophodus radiato-punctatus* occasionally occur; no other forms are known.

Reptilia.—None known.

Mammalia.—None known.

Palæontology of the Oxford Clay.

Plantæ.—The Cycadeæ stand almost alone as representing the flora of the Middle Jurassic rocks. *Bucklandia*, *Bennettites*, *Yatesia*, and *Cycadeostrobus* are the only 4 genera; together they only yield 5 species. *Cycadeostrobus sphæricus*, Carr., is the only species in the Oxford Clay.

Rhizopoda.—*Bolivina punctata*, *Polymorphina*, and *Pulvinulina Kaestini* are the only Foraminifera in the Oxford Clay. We believe there are no other known species in the Middle Jurassic strata; but 7 genera and 13 species occur in the Kimmeridge Clay.

Cœlenterata.—None known.

Echinodermata.—*Pentacrinus Fisheri*, *Amphiura Prattii*, and *Cidaris inspirata* compose the Echinodermal fauna of the Oxford Clay.

[1] Quart. Jour. Geol. Soc., vol. xv.

Annelida.—*Serpula intestinalis* and *S. vertebralis* are the only species.

Crustacea.—The Macrura, through *Glyphea leptomana*, *G. Stricklandi*, and *Mecochirus Pearcei*, constitute the Crustacean fauna. None pass to the Corallian rocks; but 2 species are Kimmeridgian.

Polyzoa.—None known.

Brachiopoda.—Five genera and 10 species range through the Oxford Clay, viz., *Waldheimia bucculenta*, *W. impressa* and *W. ornithocephala*, *Terebratula insignis* and *T. oxoniensis*, *Rhynchonella lacunosa* and *R. socialis*, *Lingula Cranæ*, *L. ovalis*, and *Discina latissima* (?). The only species that range to higher beds are *Lingula ovalis* to the Kimmeridge Clay; and *Rhynchonella lacunosa*, *Waldheimia bucculenta*, and *Terebratula insignis* to the Corallian beds.

Pelecypoda (Lamellibranchiata). *Monomyaria.*—The Oxford Clay yields 9 genera and 26 species, only 7 of which are restricted; these are *Pecten lævis*, *Ostrea hebridica*, *O. inæqualis*, *Lima argillacea*, *Gryphæa elongata*, *Avicula pterosphænia*, and *Anomia estuarina*. Thirteen species pass to the Corallian rocks, and 6 to the Kimmeridge Clay. The species common to the Oxford and Kimmeridge Clays are *Avicula dorsetensis*, *Av. inæqualis*, *Gervillia aviculoides*, *Pecten arenatus*, *P. demissus*, and *P. vimineus*.

Dimyaria.—Twenty-one genera and 48 species constitute the whole fauna of this group; 8 genera and 13 species ally the Oxford and Kellaways Dimyaria; 26 of the 48 species exclusively belong to the Oxford Clay. *Cyrena*, through the estuarine "Staffin shales," occurs for the first time in the Jurassic series, and with 6 species. In the Wealden this is the most prominent genus amongst the Pelecypoda, no less than 8 species being known in the Weald Clay. The Oxford Clay and Corallian beds are allied through 9 genera and 14 species, and 3 species range into the Kimmeridge Clay, viz., *Trigonia clavellata*, *Modiola bipartita*, and *Cardium striatulum*. There is an estuarine element in this horizon, shown by a certain facies in the Mollusca, and the genera possessing this character are the most numerously represented—*Corbula* 3 species, *Cyrena* 6, *Potamomya* 3, *Unio* 1. The estuarine element is more evident in the Dimyarian than the Monomyarian genera; it is equally manifest in the Gasteropoda, *Cerithium*, *Hydrobia*, *Littorina*, *Neritina*, *Melania*, and *Valvata* being also suggestive of this condition. In Scotland, at Loch Staffin (Isle of Skye), this was long ago determined by Professor Forbes.[1]

Gasteropoda.—Only 10 genera and 17 species are known, of which 9 are confined to the Oxford Clay. The purely Oxford-Oolite species are *Cerithium Damonis*, *Leptoxis trochiformis*, *Littorina Meriani*, *Melania inermis*, *Neritina arata*, *Paludina scotica*, *Pleurotomaria amphicœlia*, *P. Münsteri*, and *Valvata præcursor*. These restricted forms, as in almost every case through the Jurassic deposits, occur only in single species. *Pleurotomaria reticulata* is the only Gasteropod out of the 17 that passes from the Oxford Clay to the Corallian beds. The Gasteropoda, therefore, are of specific value; but, as in

[1] Quart. Journ. Geol. Soc., vol. vii. pp. 104–113.

the great argillaceous groups from the Lias up to and including the Kimmeridge Clay, the mass of the characteristic species belong to the Lamellibranchiata. The extreme poverty of species is shown by the following figures for the 10 genera:—

Alaria, Littorina, Pleurotomaria, each possessing	3	species	= 9
Neritina possesses	2	„	= 2
Cerithium, Leptoxis, Hydrobia, Melania, Paludina, and Valvata each possessing . .	1	„	= 6
			17

Cephalopoda. *Ammonites.*—No less than 45 species of Ammonites occur in the Oxford Clay, 11 of which pass to the succeeding Coralline Oolite and 4 to the Kimmeridge Clay; 20 species range from the Kellaways Rock below. The special Ammonite fauna numbers 18 species; they are stratigraphically important, and are—*A. alternans, A. auritulus, A. Bakeriæ, A. Baugieri, A. Comptoni, A. convolutus, A. Eugenii, A. flexicostatus, A. fluctuosus, A. goliathus, A. Henrici, A. Lalandianus, A. Lonsdalei, A. oculatus, A. planula, A. tatricus, A. raricostatus, A. Vernoni.* These 18 species are entirely confined to the Oxford Clay. The 4 species that pass to the Kimmeridge Clay are *A. longispinus, A. Lamberti, A. annularis,* and *A. anceps.* Very few species occur in the Oxford Clay of Yorkshire; Wiltshire, Huntingdonshire, Lincolnshire, Oxfordshire, and Western Scotland yield the chief forms. The groups represented in the Oxford Clay are the *Dentati, Flexuosi,* and *Ornati* (species of *Cosmoceras*), the *Armati* (*Aspidoceras longispinum* and *perarmatum*), the *Amalthei* through *A. cordatus, A. Lamberti,* and the *Macrocephali* through *Stephanoceras macrocephalum.* Twenty Oxford Clay species occur in the Western Isles (Scotland), in which the groups *Dentati, Ornati,* and *Flexuosi* are conspicuous, species of the genera *Cosmoceras* and *Aspidoceras* prevailing.[1]

Ancyloceras.—*Ancyloceras calloviense* is the only form occurring. It is chiefly Callovian.

Nautili.—None known.

Belemnites.—Thirteen species have been described, but probably only 10 occur, with 3 varieties of the species *B. Owenii, B. Puzosianus, B. verrucosus,* and *B. tornatilis.* Since the Inferior Oolite, which yielded 16 species, there has been no such illustration of this genus. Only 6 of the 13 species are confined to the Oxford Clay, viz., *B. Beaumontianus, B. excentricus, B. obeliscus, B. spicularis, B. strigosus,* and *B. sulcatus.*

Teuthidæ.—*Acanthoteuthis antiquus* and *Geoteuthis brevispinus*

[1] To enter into the distribution of the Middle Oolite Ammonites according to their groups and new genera would alone constitute an entire and lengthened chapter; the difficulty being to reduce any history of this group to moderate limits. D'Orbigny in this division of the Jurassic rocks (Oxfordian) of France enumerates and describes no less than 43 species of Ammonites, 12 Belemnites, and 4 *Nautili.*

illustrate this family; they are associated with the great series of Ammonites collected from the Oxford Clay of Christian Malford. *Acanthoteuthis* is the *Belemnoteuthis* of Pearce, the *Leptoteuthis* of Meyer, and the *Enoploteuthis* of D'Orbigny.

Pisces.—*Aspidorhynchus euodus, Lepidotus macrorhynchus, Leptolepis costalis*, and *L. macrophthalmus* comprise the Ichthyic fauna of the Oxford Clay, neither do they occur out of it. All the species of fish occurring in the Lias, the Lower Oolite, Middle Oolite, and Upper Oolite are totally distinct; no species unites any of the divisions, so that the range of the 61 genera and 219 species occurring in the Jurassic rocks is definite, and of great significance stratigraphically.

Reptilia.—Thirteen species representing 7 genera have been described from the Oxford Clay, namely—*Ichthyosaurus dilatatus, I. thyreospondylus, Megalosaurus Bucklandi, Murœnosaurus Leedsii, Plesiosaurus eurymerus, P. Leedsii, P. oxoniensis, P. plicatus, P. trochanterius, Pliosaurus æqualis, P. Evansi, Streptospondylus Cuvieri*, and *Priodontognathus Phillipsii;* and only two of these pass to the Corallian beds (*Pliosaurus æqualis* and *Megalosaurus Bucklandi*). Six species are specially Oxfordian, viz., *Murœnosaurus Leedsii, Plesiosaurus eurymerus, P. Leedsii, P. oxoniensis, Pliosaurus Evansi*, and *Priodontognathus Phillipsii*. The above genera illustrate the following 4 orders—the Opisthocœlian Crocodilia through *Streptospondylus*, the Sauropterygia through *Murœnosaurus, Pliosaurus*, and *Plesiosaurus*, the Ichthyopterygia through *Ichthyosaurus*, and the Deinosauria through *Megalosaurus* and *Pristodontognathus*.

Mammalia.—None known.

The Lower Calcareous Grit.

Physical Characters.—There is no strongly marked division between this and the last formation (Oxford Clay). The upper portion of the clay becomes gradually more sandy, and is poor in fossil-remains. The typical "Lower Calcareous Grit" commences where the beds become indurated. The Yorkshire Coast sections expose the Calcareous Grit as a hard yellow mural cap to the Oxford Clay, strongly contrasting with the graceful convex slope and curve of the slaty-coloured Oxford Clay below. On the summits of the eastern tabular range, and amongst the Howardian Hills, the Calcareous Grit caps the high ground, and is a marked feature in the scenery. The subdivisions in this group are petrological, rather than palæontological.

This formation constitutes escarpments comparatively bare of vegetation, and is conspicuous in the "ranges" in the interior of Yorkshire.[1]

[1] It frequently occupies the summits of the "tabular range," which largely owes its peculiar configuration to these beds. Physically and geographically these beds are important factors in the vertical proportions in the western escarpments of the Hambleton Hills. "Taken altogether, the Lower Calcareous Grit occupies more surface-ground in Yorkshire than any other member of the series between the Lower Oolites and the Kimmeridge Clay."

The Calcareous Grit constitutes the base of the Corallian series, and probably imperfectly represents the commencement of the *White Jura of the Continent.*

Fauna and Distribution.—The fossils of the Lower Calcareous Grit proper, excluding the passage-beds, are obtained from "doggers" along the Yorkshire Coast. Those from Pickering, and from the upper part of the Filey and Scarborough sections, belong to the "Greystone or Passage-beds, or sandy limestones."

The following numerical facts will give a general idea of the facies of the fauna of these Grits. The whole number comprised is 46 genera and 65 species. Zoologically classified, they are as follows:—CEPHALOPODA: *Belemnites* 2 species, *Nautili* 1, *Ammonites* 7, *Gasteropoda* 7; PELECYPODA: *Monomyaria* 12, *Dimyaria* 17, *Brachiopoda* 5, *Crustacea* 2, *Echinodermata* 7, *Actinozoa* 5, and *Protozoa* 2 species.[1]

At Scarborough Castle Cliffs, and near Filey, the Lower Calcareous Grit passes by insensible gradations into the Oxford Clay below, the main mass being composed of rough reddish-yellow grits, with siliceous bands and large sponge-like nodules arranged in lines. Nearly 80 feet of this same rock are seen in the cliff north of Filey.

The Lower Calcareous Grit is intimately connected palæontologically with the lower limestones of the Coralline Oolite above, and although they are lithologically dissimilar, and the Passage-beds exist between them, yet the fossils of the two groups may be classed as one, being indicative of a low and high position respectively, rather than characteristic of any particular bed.

The Greystone or Passage-Beds.—These beds include the *upper part* of the *Lower* Calcareous Grit, and the *lower part* of the succeeding Coralline Oolite.[2]

The central portion of these Passage-beds is locally known as the "*Grey stone*" calcareous sandstone, and is stratigraphically conspicuous. The following fine section on the north side of the Carr Naze, Filey Brigg, is 80 feet thick, and divisible into five well-defined groups, in thirty-three beds, all containing fossils. This section is highly typical of the beds above and below the Passage series, wherever exposed, and may be considered as a standard section for reference, if not a type section, affording us some clue to the history of the formation in other places, especially in the interior of the county.

TABLE LXV[A].—*Section of the Passage Series at Carr Naze, Filey Brigg.*[3]

		Ft.	In.
Upper Limestone. Oolitic.	Irregular rubbly oolitic limestone. 15 feet. White shelly limestone—*Ostrea mima, Ost. duriuscula, Pecten vimineus, P. vagans.* Fissile slabby beds.	20	0

[1] See Remarks upon the Fauna, Relations, and Affinities of the Ammonites, by W. H. Hudleston. Proc. Geol. Assoc., vol. iv. pp. 390–93.

[2] These Passage-beds are marked separately by the Geological Survey, partly on account of their peculiar lithological character, and partly from the distinct physical features which they present in their development inland.

[3] See also a most detailed description of the above by Mr. W. H. Hudleston, Proc. Geol. Assoc., vol. iv. pp. 401–5; also Q. J. Geol. Soc., vol. xxxiii. p. 318, for complete section.

TABLE LXVA.—(*Continued.*)

			Ft.	In.
		Brought over	20	0
	Middle Calc. Grit. Filey Brigg Calc. Grit.	Massive sandstone, shelly beds, hard massive grits and brown and yellow nodular grits, in 4 beds, with *Serpula*, *Gervillia aviculoides*, *Pecten subfibrosus*, *Ost. mima*, *Gryphæa dilatata*, and *Chemnitzia Heddingtonensis*.	13	0
	Grey Grits.	Hard grey grit, brown and yellow grit, hard irregular grey grits, nodular bed and comminuted shells, cherty oolitic beds. Grey gritty beds. Pale greenish grey grit, in 10 beds—*Serpula vermicularia*, *Avicula*, *Trigonia*, *Trichitis Plottii*, *Ostrea mima*, and *Gryphæa dilatata*.	11	0
Passage-Beds.	Brown and Grey Grits.	Brown sandy bed. Grey grit—*Rhynchonella Thurmanni*. Grey grit—*Rhynchonella Thurmanni*. Grey grit—*Gervillia aviculoides*. (Grey stone.) Brown sandy grits (2 beds)—*Gryphæa dilatata*, *Pecten subfibrosus*, *Ostrea mima*, *Gervillia aviculoides*.	13	9
	Ball Beds. Spongy Porous Grits.	Rhynchonella beds—fucoidal base. Spongy bed, Gervillia beds, hard grey grits, grey gritty bed, soft sandy beds, in 3 or 4 divisions, with large sponge-like doggers. 10 beds. *Pecten subfibrosus*, *Gervillia aviculoides*, *Rhynchonella Thurmanni*, *Gryphæa dilatata*, *Ostrea mima*, *Gryphæa*, sp.	20	0
			77	9

At Scarborough Castle these rocks are very accessible, and can be easily examined on the north side of the Castle Hill. The upper portion is so full of *Gervillia aviculoides*, as to well merit the term "*Gervillia* beds," applied to them (see next section, which is prepared to correlate with that of Carr Naze, Filey Brigg).

TABLE LXVB.—*Section of the Passage-Beds, &c., on the North Side of the Castle Hill, Scarborough.*

			Ft.	In.
	Lower Limestone.	Oolitic limestone in *several beds*, with *Echinobrissus scutatus*, *Ostrea mima*, *Gervillia aviculoides*, and *Trigonia*.	26	0
Passage Beds.	Grey Gervillia Beds.	False-bedded grit, soft sandy stone, parting with *Pecten subfibrosus*. Irregular spongy grit (*Cylindrites*)—soft bed, fine-grained, grey, spongy grit, fine-grained hard grey grit—*Gervillia aviculoides*, *Gryphæa dilatata*. 7 beds.	12	8
	Yellow Foxy Grits.	Yellow sandy grit, yellow grit, white grit, yellow grit, hard band of grit, shaly band, solid bed of grit. 6 or 7 courses of sandy yellow grit. *Spongy rock*—with *Rhynchonella*, *Pecten subfibrosus*, *Trigonia*, *Ammonites cordatus*. Yellow sandy grit, bright yellow soft sands with siliceous balls, hard massive grit. 17 beds.	46	0
			84	8

CHAPTER XLI.

THE CORALLIAN OOLITE SERIES.

The Coralline Oolite.[1]

THIS, the most important of the Middle Oolites, is about 70 feet thick, contains 65 genera and 115 species, and constitutes the *lower* sub-division of the *upper* Limestones, thus forming the base on which the great mass of Coral Limestone has been built up. It cannot well be separated from the overlying "Coral Rag," these two divisions of the Middle Jurassic series constituting the mass of the Upper Limestones.

Both lithologically and palæontologically, however, the Coralline Oolite presents a great contrast to the Coral Rag, the difference being mainly due to the physical conditions of deposition or sedimentation. It underlies the Coral Rag, and is not intercalated with it, having preceded it in time. *Cladophyllia cæspitosa*, *Rhabdophyllia Phillipsii*, and *Thamnastræa arachnoides* are the only three Actinozoa or Corals known.

The remains of Reptilia through *Dakosaurus*, *Megalosaurus*, and *Teleosaurus*, with the Fishes *Sphærodus*, *Pycnodus*, *Gyrodus*, and *Hybodus*, seem all that is known of the Vertebrata from the northern Coralline Oolites.

Sub-divisions.—The Corallian Rocks, as traced across England, are deposited in several areas, not left by denudation, but due to their original form of deposition or sedimentation.

These areas are of unequal magnitude and importance.[2]

The Supra-Coralline Beds.[3]—These include such portions of the beds above the Middle Oolite as are found naturally resting upon it, or in some way connected with the upper part of the formation. "They

[1] This term includes both the Coral Rag and those *oolitic limestones* which in Yorkshire succeed the variable beds occurring towards the upper part of the Lower Calc. Grit. These oolitic limestones form the lower sub-division of the Coralline Oolite (or Coralline Oolite proper) as distinguished from the overlying and different Coral Rag. The *Coral Rag* has a different fauna, and presents a marked contrast to the *Coralline Oolite*. The lower division of the Coralline Oolite is as devoid of corals as the upper division is poor in oolitic structure. Biologically and lithologically, as stated above, they strongly contrast. See Hudleston, *loc. cit.*, "Yorkshire Oolites," p. 357–8.

[2] Messrs. Blake & Hudleston, in their exhaustive paper in the Q. J. Geol. Soc., vol. xxxiii., distinguish these areas as follows:—1. The Weymouth district: 2. The N. Dorset district; 3. The N. Wiltshire district and Oxfordshire range; 4. The Cambridge Reef; and 5. The Yorkshire basin.

[3] The best exposures and finest displays of this group are shown between Filey Brigg, Seamur, Ayton, and Pickering, along the northern side of the Vale of Pickering, and on the south side of the Great Vale at Oswaldkirk and Hovingham to Malton. Consult the masterly description of the rocks comprising the Corallian group and their distribution, by W. H. Hudleston.—Q. J. Geol. Soc., vol. xxxiii., 1877, and Proc. Geol. Assoc., vols. iv. and v. *passim*.

include the Lower Calcareous Grit of Pickering and Kirkby Moorside, overlying the Coralline Oolite, as well as the remarkable argillo-calcareous beds, or cement-stones, locally termed 'throstler,' so conspicuous at Pickering and North Grimstone." These beds are not fossiliferous in comparison with the other members of the Corallian group, only 17 genera and 28 species constituting the known Yorkshire fauna.

A.—Weymouth Area.[1]—The Corallian beds of this area were deposited as a lenticular mass, having its greatest thickness near Weymouth. The base of the series is composed of Calcareous sand, with hard bands of Grit, about 30 feet in thickness.[2] The change into these beds from the Oxford Clay below is by no means gradual.

Characteristic Fossils.—The uppermost bed of the clay is surmounted by a thick layer containing *Ostrea dilatata*, associated with *Ammonites cordatus*, *Ostrea gregaria*, and the characteristic *Serpula tricarinata*. The sands of the "Nothe Grits," with *Perna quadrata*, immediately cover these. They contain a characteristic series of fossils: *Trigonia perlata*, *Pecten fibrosus*, *Avicula ovalis*, and the crinoid *Millericrinus echinatus*. Added to these there are Oxfordian species—*Belemnites hastatus*, *Ammo. cordatus*, *Ostrea dilatata*, *Cerithium muricatum*, and *Myacites decurtatus*, &c.

Nothe Clays.—Succeeding these are argillaceous beds—the "Nothe Clays" of Hudleston—also containing Oxfordian rather than Corallian types of life.[3]

Bencliff Grits.—They are succeeded by the Bencliff Grits and sands, characterised by large "Doggers" in the lower sands; *Cucullæa corallina*, *Pecten qualicosta*, *Gervillia aviculoides*, *Cerithium*, sp., *Exogyra nana*, and *Trigonia corallina*, constitute part of the fauna.

Fauna of the Osmington Series.—The "Osmington" series are next in upward succession, and measure 22 feet. The fauna of the Osmington Oolite is important, as a means of affording correlation with distant series. About 20 species are known from the Osmington Clays and Limestones, amongst them *Chemnitzia Heddingtonensis*, *Phasianella Buvignieri*, *Natica corallina*, *Opis corallina*, *Trigonia Hudlestoni*, and *Tancredia disputata*.

The more calcareous portions of the Corallian rocks follow, and are of extreme value—no less for the richness of their fossil contents, than for the lithological features which characterise the "Coral Rag." The abundance of *Trigonia clavellata* has given the name "*Trigonia beds*" to this series; they are nearly 30 feet in thickness. No less than 49

[1] This and the Yorkshire area, as possessing the most characteristic features of the Corallian Rocks, and being at the two extremes of England, are selected as types for the history of the group, but the intervening localities of Dorset and Wilts, &c., are equally important. They have been completely described by Messrs. Blake and Hudleston, and the student is referred to the whole history of the Corallian series in their memoir, Q. J. Geol. Soc., vol. xxxiii., "On the Corallian Rocks of England."

[2] These are well exhibited beneath the Nothe Fort at the end of Weymouth Pier.

[3] *Ammo. cordatus*, *Nautilus hexagonus*, *Alaria trifida*, *Thracia depressa*, *Modiola bipartita*, *Ostrea dilatata*, and *Serpula tricarinata*—in all 16 species occur.

genera and 64 species have been collected and determined by Messrs. Hudleston and Blake from these Trigonia beds.[1]

Chief Species.—The chief forms are *Ammo. cordatus, Chemnitzia Heddingtonensis, Nerinæa Goodhallii, Cerithium muricatum, Natica corallina, Cylindrites elongata, Ceromya excentrica, Opis Phillipsi, Sowerbya triangularis, Protocardium isocardioides, Trigonia clavellata, T. meriani, Cucullæa corallina, Lima rigida, Perna quadrata, Cidaris florigemma, Hemicidaris intermedia, Echinobrissus scutatus,* and *Thecosmilia annularis.*

Sands-foot Castle Beds and Fossils.—Succeeding the main Limestone and Osmington series are the "*Sandsfoot-Castle beds,*" the six subdivisions of which include strata about 50 feet thick. The lower beds, from 12 to 18 feet, are very fossiliferous, the great *Lima pectiniformis* being associated with fucoids and sponges in the calcareo-siliceous grits.

Thirty-one species of Mollusca and 3 Echinoidea have been obtained from these singular beds. *Ammonites achilles, Belemnites nitidus, Pleurotamaria Münsteri, Pholadomya hemicardia, Trigonia muricata, Pinna pesolina, Lima pectiniformis, Avicula aedilignensis,* with *Cidaris florigemma* and *C. Smithii,* are the characteristic species.

Abbotsbury Beds and Fauna.—The *Abbotsbury series,* comprising the Ironstone beds (hydrated-ferric oxide), contain also a well-marked and abundant molluscan fauna. Twenty-three genera and 30 species occur in this highly ferruginous deposit.

The characteristic *Ammonites* here are *A. decipiens* and *A. Hector,* with *Belemnites nitidus, Trigonia monilifera, Pleuromya Voltzii ;* and 5 species of Brachiopoda, viz., *Rhynchonella corallina, R. inconstans, Terebratula subsella, Waldheimia lampas,* and *W. Dorsetensis ;* with the crustacean *Glyphæa ferruginea.*

The species in these Abbotsbury beds appear to be on the horizon of the Kimmeridge Clay. Hitherto the age of these Ironstones was not understood ; their palæontological history, however, places them at the close of the Corallian beds and at the base of the Kimmeridge Clay.

The accompanying section shows the character of the deposit[2] :—

	Ft.	In.
1. Loose ferruginous sand.		
2. Granular Iron-ore, with grains about the size of a millet seed, and streaks of ferric hydrate in various directions. Fossils abundant, especially *Rhynchonella corallina* and *Waldheimia lampas*	20	0
3. Coarse ferruginous suboolitic grits in hard cherty bands with *Ammonites decipiens*	2	6
4. Yellow weathering sand ; no fossils	2	0
5. Dark-green earthy suboolitic rock highly charged with ferrous oxide	1	0
6. Dark ferruginous sandstones with variable hard beds, with *Exogyra virgula*	10	0
	35	6

[1] Numerically and zoologically they are as follows :—Cephalopoda, *Ammonites,* 2 species, *Belemnites* 7 ; Gasteropoda, 11 genera and 17 species ; Pelecypoda, *Monomyaria,* 10 genera, and *Dimyaria,* 18 genera and 24 species ; Echinoidea, 5 genera and 5 species ; and Actinozoa, 2 genera and 3 species.

[2] Blake and Hudleston, Q. T. Geol. Soc., vol. xxxiii.

B. The North Wiltshire Corallian Rocks have long been classic through the earlier researches of Smith, Lonsdale,[1] Fitton, and Phillips.[2]

This large area is divided by Messrs. Hudleston and Blake into 6 districts, each remarkable for its history.[3]

1. The Westbury district.
2. „ Steeple Ashton district.
3. „ Calne district.
4. „ Wootton Bassett district.
5. „ Faringdon to Oxford region.
6. „ N.E. of Oxford series.

1. *The Westbury District.*—The Corallian beds here have been exposed and their history revealed through the extensive workings for iron ore, the large and instructive sections being entirely due to the interest attached to the workings in the beds above the Coral Rag, and below the true Kimmeridge Clay.

The Iron Ore beds, or series containing the Ironstone, are 13 feet thick, and comprise the following details :—

	Ft.	In.
1. "Dark earthy friable stone, oolitic with band of hard blue shelly rock," containing enormous numbers of *Ostrea deltoidea* . .	2	0
2. *Ore Bed.*—"Dark-green blocks of earthy and oolitic stone (in layers 6 to 9 inches thick), with much ferric hydrate along the joints and lines of bedding[4]	7	0
3. Band of oxidised stone	0	3
4. Dark oolitic rock to floor of working	4	0
	13	3

Fauna.—The fauna of the ironstone beds, although small, is conclusive as to the position of the series. The species occurring are—*Ammonites Berryeri, A. pseudo-cordatus, Cardium delibatum, Pholadomya hemicardia, Perna quadrata, Pecten lens, P. midas, P. distriatus, Ostrea deltoidea* and *Serpula.*

Evidently these, like the Sandsfoot grits, are essentially Kimmeridgian.

2. *Steeple Ashton District.*—Lonsdale [5] has described this celebrated locality, rendering it famous from his descriptions of the coral fauna, for which its renown is world-wide. All evidence is now lost of the sections whence the corals were derived; they appear to have been ploughed up and collected from the surface. *Cidaris florigemma* has not been found; *Chemnitzia Heddingtonensis, Opis Phillipsii, Pecten qualicosta, Ostrea gregaria,* and *Exogyra nana* occur in the rubbly oolite.

3. *The Calne District.*—In this area we have, from the Oxford Clay

[1] Geol. Trans. 2nd ser., vol. iii. p. 2.
[2] Geol. of Oxford and Valley of the Thames.
[3] Blake and Huddleston, Q. Jour. Geol. Soc. vol. xxxiii.
[4] Analysis shows 42 per cent. of iron in the brown portions, and 37¾ in the green. Mr. Hudleston describes the ore as "partly a ferrous carbonate, and partly as hydrated peroxide, the condition of oxidation varying with the amount of clay which happens to cover the beds."
[5] Trans. Geol. Soc., 2nd ser., vol. iii. p. 2.

upwards, 80 feet of Corallian beds, viz., the Lower Calc. Grit, 25 feet; pale hard marls, 25 feet, and the Coral Rag, 30 feet.

Fauna of the Calne area.—The species occurring are *Ammonites cordatus, A. perarmatus, Cerithium muricatum, Gervillia aviculoides, Pholadomya concinna, Pecten fibrosus, Pecten lens, Ostrea gregaria, O. dilatata, Exogyra nana,* and *Serpula tricarinata.*

The uppermost of the Corallian beds in this area (Calne), the "*Coral Rag*" series, are historically and palæontologically interesting, and are shown by stratigraphy and fossil contents to be of the same age.

1. The true Coral Rag, full of *Thamnastrea gregaria,* and containing *Cidaris florigemma,* passing up to the Kimmeridge Clay, 30 feet.
2. False-bedded oolite, 25 feet thick, with *Hemicidaris intermedia, Acrosalenia decorata,* and *Stomechinus,* &c.

No corals occur here, the Mollusca and Echinodermata standing alone.

Hillmarton—Characteristic species.—The characteristic species are—*Cerithium muricatum, Turbo funiculus, Chemnitzia corallina, Phasianella Buvignieri, Trochotoma tornata, Lima rigida, Pecten lens, Avicula pteropernoides, Cidaris florigemma, Acrosalenia decorata, Hemicidaris intermedia,* and *Stomechinus gyratus.*

3. Twenty-two genera and 30 species have been collected here.

The species in this enumeration are characteristic of the *Cidaris florigemma* Rag (*vide* MM. Blake and Hudleston, *loc. cit.*, p. 292, for names of species).

4. **Goatacre.**—A fourth form or condition of the Rag occurs lithologically distinct from the above. The species are—*Phasianella striata, Chemnitzia Heddingtonensis, Cerithium muricatum, C. limæforme, Littorina muricata, Lucina Moriana, Lima rigida,* and *Cidaris florigemma.* These Calne rocks are here the highest *below* the Kimmeridge Clay; indications, however, occur towards Hillmarton of the presence of Supra-coralline beds.

4. *Wootton Bassett District.*—About 30 feet of the Wootton and Highworth series are exposed. The Lower Calcareous Grit is nowhere shown. The Coral Rag dominates in this neighbourhood; *Cidaris florigemma* abounds in the coarse-grained rubbly oolite. It is a true coral reef, with massive *Thamnastræan* corals. Its maximum development takes place in the neighbourhood of Purton, where the following fossils occur:—*Littorina muricata, Perna mytiloides, Pecten vimineus, Lima rudis, Avicula ovalis,* and *Cidaris florigemma.*

The beds below the Coral Rag are finely developed in the quarries near Highworth, above the Lower Calcareous Grit proper. Thirty feet of strata are seen in the section at Highworth South Quarry, where 8 beds are exhibited.

Fauna of the Beds.—No less than 29 genera and 37 species have been determined from the Coralline Oolite. CEPHALOPODA—*Ammonites* 4 species, *Belemnites* 1; GASTEROPODA 6, PELECYPODA 23; ECHINODERMATA, 3 species.

The characteristic species are *Ammonites plicatilis* and *A. cordatus, Belemnites Owenii, Phasianella striata, Chemnitzia Heddingtonensis, Pholadomya decemcostata, Gervillia aviculoides, Lima rigida,* and *Echinobrissus scutatus.*

5. *Faringdon to Oxford.*—The Corallian rocks near Faringdon may be regarded as the type and standard for comparison in the district. The total thickness of the series between the Oxford Clay and the Kimmeridge Clay is 100 feet.

There are two localities in this district where the Corallian series can be fully studied; one is the section near the Lamb Inn (6 miles

from Faringdon), and the other at Marcham field, South Quarry, where the whole sequence is shown, and illustrates the Coral Rag supported on a calcareous basis.[1] For clear insight into the sequence and relation of these Corallian divisions and their fossil contents, it is necessary and important to study these two sections.

TABLE LXVIA.—*Section of the Lamb Inn Quarry.*

	Ft.	In.
1. Deep red sandy loam unconformable to the lower beds, resting in some places on No. 2, and in others on No. 3	3	0
2. Flaggy oolitic sandy limestones, resting on sand with shelly calcareous fragments and Lydian stones	1	3
3. Siliceous sands (18 inches), graduating into brick-earth clays unconformable to the bed below, which is half cut through in places, and exposes an eroded surface	7	6
(Upper Calcareous Grit of Geological Survey.)		
4. Blue-centred shelly limestone, partially oolitic, with brashy partings—the top deeply eroded in places, forming pockets—and containing *Ammonites plicatilis, Belemnites abbreviatus, Opis Phillipsi, Trigonia perlata, T. Meriani* (abundant), *Perna mytiloides, Gervillia aviculoides, Trichites* sp., *Modiola cancellata, Pecten lens, P. qualicosta, P. fibrosus, P. demissus, Hinnites velatus*, and *Echinobrissus scutatus*	3	6
5. Blue pisolite, becoming more shelly below, with fossils similar to those of the bed above, and with *Lima rigida*	3	6
6. Blue-hearted intensely hard calcareous grit, graduating downwards into No. 7	1 ft. 4 in. to	2 0
7. Yellow and white sands, base not seen	7	0
	27	9

The deep and sandy loam (No. 1) may represent the Upper Calcareous Grit; it is overlain by Kimmeridge Clay at Faringdon, and caps other beds in the neighbourhood.[2]

The great South Quarry of Marchamfield gives the whole sequence, and illustrates the Coral Rag on its calcareous basis, the fossil contents of the Trigonia bed (No. 5) being, like the corresponding beds elsewhere, the chief repository. We give the Marcham section, as without these type illustrations the distribution of the Middle Oolite rocks under new research throughout England could not be understood.

[1] Consult Messrs. Hudleston and Blake for the fullest details of these Corallian rocks, Q. Jour. Geol. Soc., vol. xxxiii.

[2] The authors of the elaborate paper on the Corallian rocks of England referred to (Q. J. G. Soc., vol. xxxiii. pp. 304–5) lay stress upon the circumstance that bed No. 3 is overlain by Oolitic rock [which never occurs in the Upper Calc. Grit, and to which the Red Earth is *unconformable*], and is in the same position as similar beds at Highworth, &c.; it is, therefore, they believe, a continued representation of the arenaceous form of the *Infra-Coralline beds;* the erosion being an indication of the wide-spread separation in time of the Oolite Shell-beds and the Coral Rag.

TABLE LXVI[B].—*Section in Marchamfield South Quarry.*

		Ft.	in.
Coral Rag.	1. Thin-splitting, rough-bedded, blue limestone with *Thecosmilia*	2	6
	2. Rubbly coral Rag in small pieces. *Thecosmilia* and *Cidaris florigemma*	2	6
	3. Soft, irregular, thin-bedded limestones, amalgamating with the Coral Rag above. (2) *Gervillia aviculoides* 3 in. to	0	8
Lemon Calc. Grit.	4. Oolite and Oolitic brash, variable, *Ammonites plicatilis*	1	8
	5. Trigonia bed—*Trigonia perlata* (near base), *Pleurotomaria reticulata*, *Quenstedtia lævigata*, *Perna mytiloides*, *Lucina Moriana*, *Opis Phillipsi*, *Lithodomus inclusus*, *Gervillia aviculoides*	1	0
	6. Loose yellow sands, false-bedded, with thin layers of clay, abundance of *Ostrea gregaria* and *Exogyra nana* at the top; flat calcareous balls and Lydian stones at the base 1 ft. to	2	0
	7. Solid blue false-bedded Calc. Grit, the top part full of *Natica Marchamensis*. Contains also *Chemnitzia abbreviata*, and *Cerithium muricatum*, var. 8 in. to	1	0
	8. Loose sand—holds up water	0	0
		11	4

(BLAKE AND HUDDLESTON, *loc. cit.*, p. 306.)

The chief exposure of the Coral Rag proper may be examined at Bradley Farm, where 6 feet of limestone, rich in *Thecosmilia*, occur.[1] Beneath the Coral Rag, the upper part of the Lower Calc. Grit contains *Ammonites cordatus*, *Cylindrites Luidii*, *Natica clytia*, *Gervillia aviculoides*, *Ostrea solitaria*, and *Serpula tricarinata*.

6. *Series North-East of Oxford.*—Professor Phillips, in his "Geology of Oxford and the Valley of the Thames," has carefully described the Corallian rocks near Oxford; they have long been classic ground.

At the base of the quarries at Headington and Shotover we find the sands of the Lower Calcareous Grit occurring either as strong bands of stone, or as large doggers with *Ammonites varicosus*, &c.

Overlying the Calcareous Grit, many different types of rock occur. In the extensive quarries at Headington are no less than three series of beds, as indicated in the following section:—

		Ft.	in.
	1. False-bedded, comminuted shell-limestone	16	0
Coral Rag.	2. Irregular Coral Rag with *Thecosmilia*, passing into and alternating with the beds above 10 ft. to	17	0
	3. Semi-oolitic shell-bed, with *Cidaris florigemma*	7	0
	4. Pebbly bed and layers of nodules with *Ammonites cordatus*	0	8
		40	8
	5. Sands of the Lower Calcareous Grit.		

[1] The reef corals here are in perfect preservation; at Cumnor both *Thamnastræa* and *Thecosmilia* abound in the Coral Rag—with *Cidaris florigemma*, *C. Smithii*, and *Hemicidaris intermedia*?

Fauna.—The fauna of the shell-bed No. 3 contains many characteristic Mollusca, and determines the position of the Coral Rag. The following occur—*Ammonites plicatilis, Phasianella striata, Natica clytia, Astarte ovata, Gervillia aviculoides, Perna mytiloides, Corbicella lævis, Myoconcha Sœmanni, Lima lævi-uscula, Pecten lens,* and *P. vimineus,* as well as the type urchin, *Cidaris florigemma.*

Bed No. 2 (Coral Rag) is entirely composed of *Thecosmilia,* with *Pleurotomaria reticulata, Pecten vimineus, Lima elliptica,* and *Cidaris florigemma.*

Between Oxford and Yorkshire there is but one other exposure known of the Corallian Rocks, and this where it would be least expected, viz., at **Upware,** between Cambridge and Ely. Here there occurs a remarkable outlier of Coralline Oolite and Coral Rag, overlaid by Neocomian strata, rich in phosphatic remains.[1] The Corallian beds here form the base on which lie the phosphatic nodules and Neocomian sands.

Lithologically the Rag is a creamy-white irregular semi-crystalline limestone, with corals and numerous other fossils, which show this deposit to be true Coral Rag.

A large molluscan fauna occurs at Upware. No Ammonite has been found, and only one species of Brachiopoda (*Rhynchonella,* sp.) The *Gasteropoda* number 6 genera and 6 species; the PELECYPODA: *Dimyaria* 9 genera and 15 species, the *Monomyaria* 6 genera and 6 species, *Actinozoa* 4 genera and 4 species, and the *Echinodermata* 4 genera and 4 species; the all-important urchin, *Cidaris florigemma,* being abundant, together with an unknown species of *Pentacrinus.* The entire fauna (consisting of 37 species) is named by Messrs. Hudleston and Blake in their paper (*loc. cit.* p. 314).

The Yorkshire Basin.

The extensive Corallian series of this area is completely isolated from the districts previously described,—an extended line of country stretching from Cambridgeshire [the Upware or Cambridge reef being the last exposure] through the western part of Norfolk and Lincolnshire to the Humber,—and along this line there is no exposure of Corallian rocks. The Oxfordian is recognised through the Kellaways and the Kimmeridge Clay above in Lincolnshire, the former appearing again at Cave, after crossing the Humber; and the latter greatly developed in the Vale of Pickering, where it is surrounded by the whole of the Corallian series. "Acklam Wold, the most southerly portion of the Yorkshire Corallian area, is distant 130 miles from the Upware coral reef, which is sufficiently exposed to show and prove original continuity between the Oxford range and the Yorkshire basin."

The Corallian rocks of East Yorkshire are developed in great thickness and variety, unequalled even by the thickest and most

[1] Professor Bonney in his "Geology of Cambridge" has described this Corallian and Neocomian outlier; it is also termed by Professor Seeley in his "Index to the Fossil-remains of Aves, Ornithosauria, and Reptilia," the "Upware Limestone;" and he places it in the series above the clay equivalent of the Coral Rag. There is, however, no doubt of its age.

varied portion of the Weymouth district, with which alone can they be paralleled or correlated.

The authors of "*The Corallian Rocks of England*"[1] divide the Yorkshire Corallian area into 4 districts where the development is fairly similar. These minor geographical areas are—

1. The Scarborough District.
2. „ Pickering District.
3. „ Hambleton District.
4. „ Howardian District.

A. The Scarborough District.—In this district is included the area between Filey and Brompton on the South, and Scarborough and Hackness on the North.

Filey.—The Corallian beds exposed here are—

	Feet.	in.	
1. The Upper Calcareous series	14	0	thick.
2. „ Filey-Brigg Calc. Grit.	10	0	„
3. „ Lower Calcareous series	26	0	„
4. „ Lower Calc. Grit proper	60	0	„
	110	0	

TABLE LXVII.—*Sequence of the Corallian Beds of Scarborough.*

	Feet.	in.	
1. *Upper Calcareous series*—			
(*a*) Broken thin-bedded Oolites (Coralline Oolite) few fossils, *Cerithium limæforme Actæonina, Echinobrissus scutatus, Holectypus*, &c., ...	5	0	thick.
(*b*) Coarse Gritty Limestones with large Oolitic granules, (Passage-beds, the oolites and the grit of Filey-Brigg)	8	0	„
(The fossils in this series (*b*) are abundant, containing *Ammonites cordatus, A. goliathus, A. plicatilis; A. perarmatus; Chemnitzia Heddingtonensis, Littorina muricata*, and *Pleurotomaria Münsteri, Gervillia aviculoides* (fine), *Pecten fibrosus*, &c.; *Trigonia* sp. (clavellatæ), *Pholadomya decemcostata, Myacites jurassi*, and *Gresslya peregrina*, &c. Eighteen genera and 23 species occur.)			
2. *Filey-Brigg Calc. Grit*—			
Massive yellow calc. grits (poor in lime), *Ostrea bullata* (large var.), *Avicula ovalis*, and *Perna quadrata*,	10	0	„
3. *The Lower Calcareous Series*—			
(*a*) Thin alternations of hard gritty Limestones and softer yellow calc. grits—rough Oolitic Limestone in 2 beds, 4 feet from the top, with *Chemnitzia Heddingtonensis*, &c., *Rhynchonella Thurmanni*, &c.	15	0	„
(*b*) Sub-oolitic gritty Limestones, and calc. grits full of dichotomising forms, very fossiliferous, many Brachiopoda distinguishing these beds from the Filey-Brigg calc. grits	11	0	„
This bed (*b*) is rich in fossils (20 genera and 25 species)—*Ammonites cordatus, A. goliathus*, and *A. perarmatus, Gryphea dilatata, Gervillia aviculoides, Exogyra nana*, and *Isocardia tenera—Terebratula Fileyensis, Waldheimia Hudlestoni, Rhynchonella Thurmanni*, &c. *Pseudodiadema versipora, Acrosalenia decorata, Echinobrissus scutatus*, and *Serpula tricarinata.*			

[1] *Op. cit.*

TABLE LXVII.—(*Continued.*)

	Ft.	In.	
' Brought forward . .	49	0	thick.
Lower Calcareous Grit proper succeeds these.			
4. *Lower Calcareous Grit.*			
(*a*) Soft calcareous sands with huge doggers in three or four layers. *Rhynchonella Thurmanni* (as in 3 *a*[1]), *Trigonia triquetra*, *Pinna lanceolata*, *Ostrea solitaria*, *Collyrites bicordatus* near the base . . 12 in. to	15	0	„
(*b*) The above (*a*) based upon a hard gritty blue rock, divided into two beds, cherty. This bed is distinguished on the Scar and in the cliffs to the W. by its mural outline, the overlying soft "ball bed sands" weather to show it. The fossils are chalcedonised .	6	8	„
(*c*) Hard blue siliceous limestones and lines of doggers alternating with softer grits, *Belemnites hastatus*, *Ammonites perarmatus*, *A. cordatus*, *Gryphæa dilatata*, *Pecten fibrosus*, *Perna quadrata*, *Rhynchonella Thurmanni*, and *Astropecten rectus*			
Total thickness down to the Oxford clay about .	40	0	„
	110	8	„

The Corallian series in the interior is finely seen North of the Forge Valley. The gorge of the Derwent on its passage through the tabular chain cuts across the several formations as they dip to the South, and exposes 136 feet of strata.[1]

B. The Pickering District.—In the Newtowndale gorge, at the outlet of which is the town of Pickering, a complete section of all the Corallian beds of this district is obtained. The upper portions of these rocks are finely displayed in the numerous quarries, as proved in the deep gorge of Newtowndale. They are as follows:—

	Feet.
Supra-Coralline beds	20
Upper Limestones	50
Trigonia beds and Middle Calc. Grit	45
Lower Limestones, including Basement or Passage-beds .	90
Lower Calc. Grit[2]	100
	305

The following is a description of the generalised section in the Vale of Pickering,[3] the most important through the Corallian series:—

[1] See Q. J. Geol. Soc., vol. xxxiii. pp. 321-23, for complete description of the Forge Valley section, which is a key to the sequence of the Corallian Limestones, and a good introduction to their development in Yorkshire.

[2] The Lower Calcareous Grit can hardly be less than 100 feet thick; towards the top occurs the usual ball-bed series.

[3] Messrs. Blake and Hudleston give in their paper (*loc. cit.*) a detailed description of the generalised section of the Pickering Oolites, extending over 16 pages.

TABLE LXVIII.—*Sequence of Coralline Beds in the Vale of Pickering.*

Upper Division.—(Supra-Coralline) grits, shales, &c.

		Ft.	in.
Upper Division.	*a.* Upper Calcareous Grit, with abundance of tuberous and ramifying forms, and many fossils in bad preservation	7	0
	b. Sandy and marly shales resting upon a thin bed of *Ostreæ*	10	0
	c. Bed of argillo-calcareous stone, locally termed "throstler." Wanting in places, or represented by a flaggy parting of a few inches	3	0
		20	0

Middle Division.—Upper Limestone.

Middle Division.	*d.* Top-stone—a grey ferruginous limestone generally false-bedded, thicker on the west than on the east side of the Valley	5	0
	e. Inferior Earthy Limestone, known as "Black Posts," poor in fossils, contains *Belemnites abbreviatus*, and towards the base *Ammonites varicostatus*	10	0
	f. Chemnitzia-Limestones, compact and sub-oolitic shell-beds at intervals full of *Chemnitziæ* and *Nerineæ*, *Astarte ovata*, &c.	20	0
	g. Variable Limestones and Pisolites, with shell-beds and nests of *Thamnastræa arachnoides* in the lower part—indications of Calc. Grit towards the base	13	0
		48	0

Lower Division.—Shell beds and grits (Middle Calc. Grit in part).

Lower Division.	*h.* The upper part of this division contains the principal Trigonia beds, full of fossils (see detailed list), alternating with Calc. Grits—*Ammonites plicatilis* abundant—building-stones, &c.	17	0
	i. Calc. Grits begin to predominate, base not seen, *Nautilus hexagonus* and *Ammonites cordatus* group[1]	11	0
		28	0

C. The Hambleton District.—This area embraces the north-west and west sides or escarpments of the Hambleton Hills, by Arden Moor and Black Hambleton, to the Vale of Pickering. Many important sections occur west of the Howardian Hills, differing but little from those described. At Ampleforth Beacon, Oswaldkirk, Nunnington, &c., the true Coral Rag beds appear, and the thickest beds of Upper Calcareous Grit in Yorkshire also occur at Nunnington, with the Coral shell-bed below, all fully fossiliferous.

The Coral Rag of Oswaldkirk contains the spines of *Cidaris florigemma* in profusion, as well as *Thecosmilia*, *Montlivaltia dispar*, *Stylina tubulifera*, and other reef-building corals. Few or no Cepha-

[1] On pp. 335–340 of the Q. Jour. Geol. Soc., vol. xxxiii., the authors named give a *detailed* description of the above generalised section.

lopoda occur in the rocks of this district. Between 30 and 40 species range through the Hambleton series.

D. The Howardian Hills District.—This fourth district of the Corallian rocks of Yorkshire includes the inner portion of the range of hills which bounds the Vale of Pickering on the south-west. East of the Derwent valley, this range is buried beneath the lofty Chalk wolds. The Corallian rocks are grouped in the Howardian district under two heads—[1]

1. Those west of the Derwent, and
2. Those east of the Derwent.

Lower Calcareous Grit and Passage-Beds.

1. **West of the Derwent.**—In the Castle Howard Park Quarry the typical Calcareous Grit is exposed as a light porous rock. Large *Aptychi* and Phragmacones of large Belemnites occur, with much drifted coniferous wood.

Fauna.—*Ammonites cordatus, A. vertebralis, A. perarmatus,* and the phragmacones of *Bel. abbreviatus* are common. *Exogyra nana, Rhynchonella Thurmanni, Collyrites bicordatus,* and *Holectypus depressus* are the chief fossils found in the Lower Calcareous Grit at Appleton. Between Hovingham and Malton the Passage-beds[2] and Lower Calcareous Grit contain *Rhynchonella Thurmanni, Nautilus hexagonus, Ammo. cordatus, A. goliathus, A. plicatilis, A. perarmatus — Waldheimia bucculenta, Terebratula Fileycnsis, Echinobrissus scutatus,* and *Millericrinus echinatus.*

. . . . . .

Coralline Oolite (*a*).—The upward succession in the Howardian area is best seen on the east side of Malton, where the great quarries in the Coralline Oolite have long been known. The following section at the Cross-roads Quarry, Peasy Hills, is important, as affording the key to the succession in the higher beds :—

			Ft.	in.
Coral Rag.	*a.*	Soil brash, which is coralline, containing spines of *Cidaris florigemma*	7	0
Coralline Oolite.	*b.*	White oolite, not very fossiliferous	13	0
	c.	Shelly oolites	9	0
		Compact fine-grained oolites	2	6
			31	6

The White Oolite (*b*) contains *Phasianella striata,* which is plentiful near the base. In the same bed were obtained many remarkable coniferous fruits. A new form of *Araucarites* (*A. Hudlestoni,* Carr.), belonging to the Colymbea section of the genus, was found by Mr. Hudlestone, and described by Mr. Carruthers,[3] under the name *Araucarites Hudlestoni.* The *Araucarites sphærocarpus* from the Inferior Oolite of Bruton, and the *A. pippingfordensis* from the Wealden of Pippingford, belong to the same section.

[1] *Loc. cit*, p. 361.

[2] The Middle Grits and Lower-Sandstone Passage-beds were first observed and made known by Mr. Fox Strangways of the Geol. Survey.

[3] Q. Jour. Geol. Soc., vol. xxxiii. p. 402 to xvii. f. 1, 2, 3.

The Shelly Oolites and Compact Fine-grained Oolites (*c*).—The *Chemnitzia* beds of the Coralline series contain the bulk of the fossils, viz., *Chemnitzia heddingtonensis*, *Nerinæa*, *Astarte ovata*, *Lucina aliena*, *Ammonites plicatilis*, *Cerithium muricatum*, *Phasianella striata*, *Pecten lens*, *Lima lævisculà* (type form), *Cyprina corallina*, &c.

The general character of the Coralline oolite of the Howardian district is to be arrived at from a study of the Malton rocks and area.[1]

Coral Rag (*d*).—East of Derwent, near Hovingham, there are extensive exposures of the reef-like variety of the Coral Rag, containing *Cidaris florigemma*, *Pecten vimineus*, *Exogyra nana*, *Hemicidaris*, sp., *Pseudodiadema hemisphæricum*, and *Terebratula insignis*.

At Hovingham Lime Quarry occurs the following section of the Coral Rag, resting upon Coralline oolite :—

		Ft.	in.
Coral Rag.	1. Broken fissile rag	4–5	0
	2. Hard coral limestone, in massive undulating beds with rounded terminations	15	0
	3. Coral shell bed (not constant); the lower portion contains *Rhabdophyllia*; the upper *Thecosmilia*, enormous spines of *Cidaris florigemma*, *Exogyra nana*, *Astarte*, and *Glypticus hieroglyphicus*, &c.	3	0
	4. Softish oolites—beneath the Coral Rag.[2]		
		23	0

2. **East of the Derwent.**—This is the smaller section of the Howardian district. It comprises the high land of Langton Wold, the southern ridge of which is continued eastwards in North Grimston Hill, where the Howardians are buried beneath the Chalk.

In this area the Lower Calcareous Grit is of much importance as a formation, being the only group left of all the Corallian beds south of Mount Ferrant, between the Oxford and Kimmeridge Clays. It is 80 feet thick over Acklam, and contains abundance of *Ammonites cordatus* or *A. vertebralis*.

"S. of Acklam, the Calc. Grit becomes gradually dimished in thickness as far as Hanging Grimston, finally dying away in the Vale of Kirby Underdale, and the two Clays (the Oxford and Kimmeridge) unite." The researches of MM. Hudleston and Blake prove "that the separation of the Yorkshire basin is due to *non-deposition*, and *not* to *denudation*" (*op. cit.*, p. 373).

The chief importance of the Corallian beds in this portion of the Howardian Hills centres in those of the age of the Coral Rag, and subsequent to it. On the high ground of Langton Wold, the Coral Rag may be said to culminate in physical development as well as in richness of fossil contents. There is no such display of this class of rock elsewhere in England.

[1] The fauna of the Malton oolite (Coralline oolite) is a large and important one, probably the richest of the Coralline rocks in the Yorkshire basin. Forty-five genera and 75 species illustrate the Malton beds alone.

[2] Vide Messrs. Hudleston and Blake, *loc. cit.*, pp. 369–72, for every particular relative to the Coral Rag of Hovingham, Cawton, Slingsby, and Hildenley Heights, &c.

The following section represents the succession and structure of North Grimston Hill from the Lower Calcareous Grit to the Supra-coralline beds and Kimmeridge Clay. The total thickness of the beds in the escarpment is 163 feet :—

Sequence and Structure of Coralline Rocks, Grimston Hill.

1. *The Lower Calc. Grit.*—This may have commenced earlier in some places than in others. Judging by the thickness of the Oxford Clay below, it may have begun very early in the Tabular Hills, but not early at Weymouth. In the Weymouth district, the Lower Calcareous Grit is represented by the "*Nothe Grits.*"

2. *The Lower Limestone or Hambleton Oolite.*—"This mass is so intimately connected by its fauna with the *Lower Calcareous Grit*, that it may be represented elsewhere than in Yorkshire by some portion of it. Its place, however, is nowhere recognisable in the south, unless it be near Sturminster, in the Oolites which *underlie the Pisolites*, or at Weymouth in the 'Nothe Clays.'"

3. *The Middle Calcareous Grit.*—"This, also, is nearly peculiar to Yorkshire, unless we place the 'Nothe Grits' on the horizon of the Hambleton Oolites, and assume the Bencliff Grits to represent this in the Weymouth area."

4. *The Coralline Oolite.*—"This mass of limestone is developed beneath the Coral Rag, with which it has been usually confounded. In Yorkshire it is a massive limestone. The Oolite in Upware North Pit, '*Cambridge reef*,' is its nearest local representative to Yorkshire. Its equivalent begins again to the west of Oxford, reaching beyond Highworth, where, and at Faringdon, are fine developments, which may be correlated with the Coralline Oolite. At Calne it appears as a marl; at Steeple Ashton and Westbury, under both forms, the marl being below. In the Weymouth area, the Osmington Oolites represent the lower portion, and the Trigonia beds the Upper."

5. *The Coral Rag.*—"Corals are usually, but not universally, associated with *Cidaris florigemma*, which gives the term '*Florigemma rag*' or 'zone'—sometimes convenient, since by this fossil, in the absence of corals, the corresponding beds may be most easily recognised."

6. *The Supra-Coralline Beds.*—This name is used for the uppermost portion of the series. They consist of calcareous grits and clays, and belong to two separate divisions. *First and lowest* are the Sandsfoot clays and grits of Weymouth, which appear to represent beds deposited between the epoch of the Coral Rag deposits and the ordinary Upper Calcareous Grit of most other localities—having in some respects a highly Kimmeridgian fauna, but also a marked community of forms with the Coral Rag. *Second and highest*, the Upper Calcareous Grit of Yorkshire, which is local even there.

Table LXX (on pp. 468 and 469), by Mr. Hudlestone, epitomises the entire history of the Corallian Rocks of Yorkshire.

The accompanying Table exhibits numerically the comparative

faunal value of the Corallian series for the two widely separated areas, (1) Dorset, Wiltshire, and Cambridgeshire, and (2) Yorkshire. The Weymouth and North Dorset deposits average 55 genera and 90 species, the Yorkshire distribution being 110 genera and 169 species, or proportionally *less rich in species* than the southern equivalents. The Table reveals the unequal distribution of life, or total absence of many groups locally :—

TABLE LXIX.—*Fauna of the Coral Rag.*

Classes.	Genera.	Species.	Dorset.		N. Wilts.	Cambridge Reef.	Yorkshire.			
			Weymouth.	N. Dorset.			Scarborough.	Pickering.	Hambleton.	Howardian Hills.
Plantæ	4	6	...	$\frac{2}{2}$	...	...	...	...	...	$\frac{2}{2}$
Spongida	2	2	$\frac{1}{1}$	...	...	...	$\frac{2}{2}$	...	...	...
Foraminifera	...	...	...	...	...	...	...	...	...	...
Actinozoa	5	7	$\frac{2}{3}$	...	$\frac{2}{2}$	$\frac{4}{4}$	...	$\frac{2}{3}$	$\frac{4}{4}$	$\frac{3}{3}$
Echinodermata	14	15	$\frac{7}{10}$	...	$\frac{6}{7}$	$\frac{8}{8}$	$\frac{5}{5}$	$\frac{3}{3}$	$\frac{3}{3}$	$\frac{7}{10}$
Annelida	1	5	$\frac{1}{5}$	$\frac{1}{2}$	$\frac{1}{2}$	...	$\frac{1}{1}$	...	...	...
Crustacea	1	2	$\frac{1}{1}$	...	...	...	...	...	...	$\frac{1}{1}$
Polyzoa	...	...	...	...	...	...	...	...	...	...
Brachiopoda	5	13	$\frac{5}{7}$	...	$\frac{3}{4}$	$\frac{1}{1}$	$\frac{3}{4}$	$\frac{2}{2}$	$\frac{2}{2}$	$\frac{2}{2}$
Monomyaria	14	51	$\frac{18}{27}$	$\frac{7}{10}$	$\frac{10}{26}$	$\frac{6}{6}$	$\frac{12}{26}$	$\frac{11}{21}$	$\frac{10}{16}$	$\frac{13}{24}$
Dimyaria	38	88	$\frac{24}{41}$	$\frac{10}{15}$	$\frac{18}{28}$	$\frac{9}{15}$	$\frac{16}{25}$	$\frac{17}{16}$	$\frac{7}{7}$	$\frac{22}{42}$
Gasteropoda	22	46	$\frac{15}{25}$	$\frac{13}{18}$	$\frac{14}{16}$	$\frac{6}{6}$	$\frac{16}{21}$	$\frac{8}{8}$	$\frac{7}{13}$	$\frac{15}{23}$
Ammonites	1	10	$\frac{1}{6}$	$\frac{1}{1}$	$\frac{1}{7}$	...	$\frac{1}{6}$	$\frac{1}{1}$	$\frac{2}{2}$	$\frac{1}{11}$
Nautilus	1	2	$\frac{1}{1}$	...	$\frac{1}{1}$	...	$\frac{1}{1}$	$\frac{1}{1}$	...	$\frac{1}{2}$
Belemnites	1	4	$\frac{1}{2}$	$\frac{1}{2}$	...	...	$\frac{1}{1}$	$\frac{1}{3}$	$\frac{1}{1}$	$\frac{1}{4}$
Teuthidæ	...	...	...	...	...	...	...	...	...	...
Pisces	...	...	...	...	...	...	...	...	...	...
Reptilia	1	1	$\frac{1}{1}$	...	...	...	...	...	...	...
	110	252	$\frac{75}{136}$	$\frac{34}{51}$	$\frac{53}{95}$	$\frac{33}{54}$	$\frac{58}{98}$	$\frac{46}{86}$	$\frac{41}{67}$	$\frac{76}{131}$

Palæontology of the Corallian Rocks.

Plantæ.—Four genera and 7 species occur, all confined to these rocks, and with the exception of 2 species, the last we know of the Jurassic flora. The Coniferæ and the Cycadeæ are the two families represented. *Araucarites Hudlestoni* is the only Conifer; *Bennettites Peachianus*, *Bucklandia Milleriana*, *Yatesia crassa*, and *Y. Joassiana* represent the Cycadeæ. *Carpolithes Bucklandi* and *C. conicus* must be doubtfully referred.

Protozoa.—*Scyphia cylindrica* and *Spongia floriceps* are all that are known.

Cœlenterata.—Nearly all the Actinozoa of the Corallian rocks are compound or branching forms, the exceptions being *Montlivaltia dis-*

TABLE LXX.—*Yorkshire Basin. Generalised Scheme of Corallian Limestones and Associated Beds.*

Formation.	Topographical Divisions and Varieties.	Localities.	Lithology—Remarks.	Some of the Characteristic Fossils.
A. SUPRA-CORALLINE, 15–40 ft., wanting in places.	1. Upper Calcareous Grit flanking the western part of the Vale of Pickering. 2. Argillo-calcareous beds (Throstler) of the same locality. 3. Argillo-calcareous beds (Cement stones) of the Howardian Hills.	Pickering, Kirkby Moorside, Helmsley, Oswaldkirk. Pickering, Appleton Common, near Kirkby Moorside. Hildenley, Burdale, Langton.	Reddish Calc. Grits, often cherty, with sometimes marly shales. Dirty earthy Limestones, very unfossiliferous. Hard calcareous bands and soft sub-calcareous shales.	*Belemnites nitidus*, Dollf. *Am. varicostatus*, Buckl. *A. alternans*, von Buch. *Ostrea bullata*, Sow. *Gryphæa subgibbosa*, Bl. & H. *Pecten Midas*, D'Orb. *Modiola cancellata*, Röm. *Lucina aspera*, Buvig. *L. substriata*. Röm. *Thracia depressa*, Phil. *Goniomya*, *Pleuromya*, *etc.*
B. CORAL RAG, sub-zone of *Cidaris florigemma*. 12–40 ft.	1. Rag of the Scarborough district, without *Cidaris florigemma*. 2. *Florigemma*-Rag flanking the western part of the Vale of Pickering, on both sides. 3. *Florigemma*-Rag of Langton Wold.	Ayton, Brompton, Hackness. Sinnington, near Kirkby Moorside, Helmsley, Oswaldkirk, Slingsby. Hildenley, Langton Wold, North Grimston.	Boulders of *Thamnastræa concinna*, and branches of *Rhabdophyllia* in an intercoralline brash. Variety of Corals; often massive, sometimes compact and cherty, rarely oolitic. Compact Limestones; massive Coral Bands, shelly brash, rarely oolitic.	*Am. varicostatus* (Buckl.) var. of *A. plicatilis*. *Purpuroidea nodulata*, Y. and B. *Natica maxima*, Y. and B. *Cerithium limæforme*, Rœm. *Nerinæa Rœmeri*, Goldf. *Littorina muricata*, Sow. *Turba funiculatus*, Phil. *Ostræa duriuscula*, Phil. *Pecten vimineus*, Sow. *Lima pecteniformis*, Schloth. *Arca quadrisculata*, Sow. *Astarte rhomboidalis*, Phil. *Opis virdunensis*, Buvig. *Terebratula insignis*, Schübl. *Cidaris Smithii*, Wr. *C. florigemma*, Phil. *Hemicidaris intermedia*, Flem. *Pseudodiadema hemisphæricum*, Ag.—CORAL RAG.
C. CORALLINE OOLITE. 20–35 feet.	1. Oolites underlying the Rag of the Scarborough district. 2. *Chemnitzia*-limestones, compact or suboolitic; impure earthy limestones. *Trigonia*-beds at base. 3. Oolites of the Howardian Hills in part.	Seamer, Forge Valley, Brompton Keld, Pickering, Kirkdale, Sproxton, Ampleforth Beacon. Malton, Settrington.	Fine white Oolites, with Coral-shell Beds in the upper part. Usually compact creamy Limestones with sparry shells, calcareous Pastes, with Oolitic granules. Clean white Oolites, sometimes a little marly, burnt for lime.	*Belemnites abbreviatus*, Mill. *A. plicatilis*, Sow. *A. cordatus*, Sow. *Chemnitzia heddingtonensis*, Sow. *Nerinæa visurgis*, Röm. *Cerithium muricatum*, Sow. *Pecten intertextus*, Röm. *Cucullæa corallina*, Damon. *Trigonia Meriani*, Ag. *T. perlata*, Ag. *Lucina aliena*, Phil. *Astarte Duboisiana*, D'Orb. *Pygurus Hausmanni*, K. and D.—CORALLINE OOLITE. N.B.—The top shell-bed of the Lower Limestones is included with the Coralline Oolite palæontologically.
C¹. MIDDLE CALCAREOUS GRIT. 10–45 feet.	The *Trigonia*-beds at the top of this series in the Pickering district are referred palæontologically to the Coralline Oolite.	Filey Brigg, Pickering, Duncombe Park, Wass Moor. Not proved in the Howardian Hills.	An arenaceous Calc. Grit, sometimes with Shell-beds, where it graduates into the overlying series. Building.	

Zone of A. plicatilis.

TABLE LXX. (*continued*)—*Yorkshire Basin.*

Formation.	Topographical Divisions and Varieties.	Localities.	Lithology—Remarks.	Some of the Characteristic Fossils.
D. LOWER LIMESTONES. 20–120 feet.	*Upper Division.* 1. Oolites underlying the M.C. Grit of the Tabular Hills.	Scarborough Castle. Lime quarries of Silpho and Suffield. Forge Valley, Thornton, Cropton.	Small-grained Oolites, frequently rather gritty, much used for lime.	*Upper Part of Zone of A. peramatus.* ***Belemnites abbreviatus***, Mill. ***A. peramatus***, Sow. ***A. cordatus***, Sow. (*excavatus*). ***A. goliathus***, D'Orb. ***Cylindrites elongatus***, Phil. ***Avicula ovalis***, Phil. ***A. expansa***, Phil. ***Pecten fibrosus***, Sow. *Gervillia aviculoides*, Sow. ***Myacites Pholadomya***. *Echinobrissus* ***scutatus***, Lam. ***Holectypus***.
	2. Oolites sometimes split by a fourth grit, of the Hambleton Hills.	Hawnby Hill top, Kepwick, Cold Kirkby, above Rievaulx.	Gritty small-grained Oolites, often very impure, quarried for lime and roadstone.	
	3. Oolites of the Howardian Hills in part.	Broughton, Swinton.	Thick-bedded Oolites, formerly much burnt for lime.	
	Lower Division. 1. Passage-Beds at base of the Lower Oolite in the eastern districts.	Scarborough Castle, Hackness (Lower Coral Rag), Filey Brigg, Wydale.	Coarse gritty Limestones, often ferruginous.	***Ammonites Williamsoni***, Phil. ***A. goliathus***, D'Orb. *Avicula ovalis*, Phil., and *expansa*, Phil. *Gervillia aviculoides*, Sow. *Trigonia clavellata?* Sow. *T. triquetra*, Von Seeb. *T. Snaintonensis*, Lyc. *Sowerbya triangularis*, Phil. *Waldheimia buculenta*, Sow. *W. Hudlestoni*, Walk. *Terebratula fileyensis*, Walk. ***Rhynch. Thurmanni***, Voltz. ***Glyphœa rostrata***, Phil. ***Millericrinus echinatus***, Goldf. ***Spongia floriceps***, Phil.
	2. Cherty Limestones of the Western districts.	... ...		
	3. Basement Limestones above the L. C. Grit of the Howardian Hills.	Appleton, Brows quarry (Malton).	The basement beds not well distinguished here. Fig-seedy Limestones, with much grit—used for building and road stones.	
E. LOWER CALCAREOUS GRIT Proper. N.B. — The above figures do not represent the absolute *maxima* and *minima* of each formation.				

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par and *Protoseris Waltoni*. The remaining species are—*Comoseris irradians, Goniocera socialis, Isastræa explanata, I. Greenoughii, Rhabdophyllia Phillipsii, R. Edwardsii, Stylina de la Bechei, S. tubulifera, Thamnastræa arachnoides, T. rotata, Thecosmilia annularis*, and *Calamophyllia Stokesii*. Except one species (*Thamnastræa arachnoides*), which is also Cornbrash, all are confined to the Coral Rag. This special Coral fauna is the largest since the deposition of the Great Oolite, which yields 15 genera and 38 species. None are known either in the Kellaways Rock, Oxford or Kimmeridge Clays.

Echinodermata.—Fifteen genera and 28 species; 26 of these are entirely confined to the Corallian beds. *Echinobrissus dimidiatus* and *E. orbicularis* are also Cornbrash. *Millericrinus echinatus* is the only Crinoid, and *Astropecten rectus* the only Asteroid. The group Endocyclica is represented by 6 genera and 11 species, and the Exocyclica by 7 genera and 15 species; they are—

Endocyclica.	Cidaris	2	species.	*Exocyclica.*	Clypeus	1	species.
	Glypticus	1	„		Collyrites	1	„
	Hemicidaris	1	„		Echinobrissus	5	„
	Hemipedina	2	„		Holectypus	1	„
	Pseudodiadema	4	„		Hyboclypus	1	„
	Stomechinus	1	„		Pygaster	1	„
		11			Pygurus	5	„
						15	

Annelida. — Seven species comprise all the known Corallian Annelida; 5 are Serpula and 2 Vermicularia.

Crustacea.—*Glyphæa ferruginea* and *G. rostrata* are the only 2 species known; the latter ranges from the Inferior Oolite.

Polyzoa.—Two doubtful species, *Heteropora conifera* and *Terebellaria ramosissima*.

Brachiopoda.—Twenty-one species, representing 7 genera, viz., *Terebratula, Waldheimia, Rhynchonella, Lingula, Discina, Zelania*, and *Thecedium*. *Discina Humphresiana* ranges into the Kimmeridge Clay, and is the only species connecting the two horizons.

Pelecypoda (Lamellibranchiata). *Monomyaria.*—Fourteen genera and 58 species occur; of these only 16 are true Corallian forms. Seven genera and 15 species pass to the Kimmeridge Clay, 9 genera and 13 species unite the Oxford Clay below with the Corallian. The genera most largely represented are *Avicula* 7, *Lima* 8, *Pecten* 5, and *Ostrea* 9. *Plicatula, Pteroperna, Trichites*, and *Gervillia* one each. *Perna, Pinna, Hinnites*, and *Placunopsis* with two. *Exogyra nana, E. spiralis, Lima rustica, Ostrea solitaria*, and *Perna mytiloides* range to the Portland beds.

Dimyaria.—Twenty-nine genera and 93 species are known; 47 of the 93 are confined to the Corallian beds. Nine genera and 14 species also occur in the Oxford Clay, and 10 genera and 12 species pass to the Kimmeridge Clay. *Astarte, Arca, Modiola, Lucina, Pholadomya*, and *Trigonia* are the genera most largely represented.

Gasteropoda.—With the exception of 7 species, the whole of the

PLATE XXII.

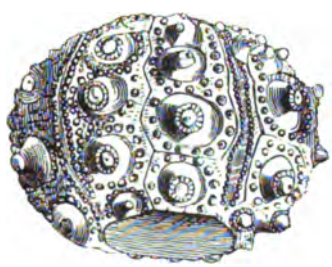
MIDDLE JURASSIC FOSSILS.

1. *Trigonia clavellata* (Park). Kimmeridge Clay and Portland Sand. Weymouth, Swindon, &c.
2. *Ostrea gregaria* (Sow.) Corallian beds. Yorkshire, Wiltshire, Cambridgeshire.
3. *Nerinæa Goodhallii* (Sow.) Corallian beds. Dorsetshire (Osmington, &c.)
4. *Gryphæa dilatata* (Sow.) Corallian and Oxfordian Rocks. Wilts, Yorkshire, Oxfordshire, &c.
5. *Littorina muricata* (Sow.) Corallian beds. Wiltshire, Yorkshire, Cambridgeshire.
6. *Cidaris florigemma* (Phill.) Coral Rag. Calne, Yorkshire, &c.

PLATE XXII.

MIDDLE JURASSIC FOSSILS.

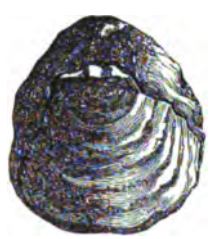
1



6

2

3



4

5

known 67 are confined to the Corallian rocks. *Pleurotomaria reticulata* passes to the Kimmeridge Clay. The only form uniting the Oxford Clay and Coral Rag is *Littorina muricata;* but 5 of the Kellaways species bridge over the Oxford Clay and reappear in the Corallian; they are *Pleurotomaria granulata, Dentalium annulatum, D. entaloideum, Alaria bispinosa,* and *Actæon retusus.* Probably in no other horizon in the British rocks are the Gasteropoda so distinctive of the beds they occupy; for we have seen that out of the 67 species occurring, 60 *are peculiar to, or characteristic* of, the beds they illustrate.

Cephalopoda. *Ammonites.*—Twenty-one species, 9 of which are essentially Corallian; they are *A. anceps-albus, A. Babeanus, A. cadonensis, A. rupellensis, A. plicatilis, A. pseudo-cordatus, A. retroflexus, A. Sutherlandiæ* (*goliathus*), and *A. Williamsoni.* Eleven of the 21 species occur in the Oxford Clay, and 2 pass up to the Kimmeridge Clay (*A. achilles* and *A. longispinus*). *A. macrocephalus* connects the Lower and Middle Oolitic rocks.

Nautili.—*Nautilis hexagonus* is the only known species; it had previously occurred in the Cornbrash and Kellaways Rock.

Belemnites.—*B. abbreviatus* with its two varieties, *B. oxyrhynchus* and *B. excentricus,* and *B. hastatus,* constitute all the known Dibranchiata. *B. abbreviatus* also appears in the Kimmeridge Clay above.

Pisces.—*Gyrodus Cuvieri, G. punctatus,* and *Hybodus obtusus* are all that are known of this class.

Reptilia.—*Chelys Blakii, Megalosaurus Bucklandi,* and *Pliosaurus* are the only representatives, and these illustrate three orders —the *Chelonia, Deinosauria,* and *Enaliosauria* or *Sauropterygia.*

CHAPTER XLII.

THE KIMMERIDGE CLAY AND PORTLAND OOLITE.

Oak-tree Clay (Smith).

Range and Thickness.—From the great cliffs of Kimmeridge in the Isle of Purbeck, which gives name to the deposit, this Clay is traceable with little real interruption (except such as arises from the unconformability or overlap by the Cretaceous series) into Yorkshire, everywhere preserving its nearly uniform characters, composition, great thickness, and peculiar fossil remains. The average thickness of the Kimmeridge Clay may be 400 feet; near Swindon (Wilts) it is 500 feet; near Oxford, 100 feet.[1] In the deep sub-Wealden boring at Netherfield, near Battle, it was nearly 800 feet; but this was an ab-

[1] The Rev. Osmond Fisher assigns to the Kimmeridge of Osmington a thickness of 530 feet. See also Dr. Fitton, "On the Strata below the Chalk" (Geol. Trans., vol. iv. p. 213).

normal condition of deposition. The Kimmeridge Clay occupies the greater part of the Vale of Pickering in Yorkshire; it occurs in Cambridgeshire, Lincolnshire, Norfolk, Oxfordshire, Berkshire, Wiltshire (*North Wilts clay*) Swindon, and Wootton Bassett, Somersetshire and Dorsetshire, forming the chief substratum of the Isle of Portland. In the Isle of Purbeck it is freely exposed at Gad Cliff and St. Alban's Head, where it is overlaid, as at some other places, by the Portland beds.

Divisions.—The Kimmeridge Clay may be divided into two sections, Upper and Lower Kimmeridgian.

(*b*) The Upper division, or Upper Kimmeridge, consists of a series of paper shales, bituminous shales, and *cement stones*, having a maximum thickness of 650 feet in Dorsetshire, but thinning away or disappearing in the inland counties. This Zone is comparable with the "*virgulian* group" of Continental authors.

(*a*) The Lower division, or Lower Kimmeridgian, is composed of blue sandy clay, with the ferruginous concretions called "*Doggers*," having a thickness of from 300 to 500 feet, and typically developed in Lincolnshire, representing the "*Astartian* group" of the French and Germans.[1] This division is the great fossiliferous repository of the group.

On the Continent much diversity exists in the arrangement of the Kimmeridge Clay beds. The general result, however, is their separation into three Zones, viz. :—

(*a*) The Lowest, that of *Astarte supracorallina*, or the *Astartian* Zone.

(*b*) The Middle, *Pterocera oceani*, or *Pterocerian* Zone.

(*c*) The Upper, *Trigonia gibbosa*, or the Portland strata, separated as the Zone of *Exogyra virgula*, or the Virgulian.

We propose treating the Kimmeridge group separately from the Portland, as inland, or through Mid-England, up to Lincolnshire, and on to the great Vale of Pickering in Yorkshire, it has no visible Portland covering beyond Swindon, Wiltshire.

Upper Kimmeridge.—The Upper Kimmeridge Clay (*Virgulian* of Continental authors) is readily distinguishable, both lithologically and palæontologically, from the zones below. It is exclusively composed of bituminous and paper shales. In Kimmeridge Bay these shales are completely developed, and measure 650 feet in thickness.[2]

Upper Kimmeridge Fauna.—These Upper Kimmeridgian beds contain a well-marked fauna characterised by the following species :—*Ammonites biplex, Am. Thurmanni, Belemnites Souichii; Aptychus, Rostellaria*, sp., *Lucina minuscula, Arca rhomboidalis, Cardium stria-*

[1] The greatest developments of these sections are not known in the same area. The Dorsetshire, Wiltshire, Oxfordshire, and Lincolnshire series all vary in this respect,—physically this is chiefly a question of deposition. As regards the distribution of life, when the same beds occur in any area, we find no variation in the distribution.

[2] "On the Kimmeridge Clay of England," by the Rev. J. F. Blake, M.A.—Q. Jour. Geol. Soc., vol. xxxi. pp. 196–233.

tulum, *Astarte lineata*, *Exogyra virgula*, *Ostrea*, sp., *Discina latissima*, and *Avicula vellicata*, *Acanthoteuthis speciosa*.

Upper Kimmeridge with bituminous shale is known to occur in the Isle of Portland; it is thin or absent at Swindon, but occurs at Shotover.

The Upper Kimmeridge is known at Ely, and contains in the paper shales *Discina latissima*, *Lucina minuscula*, and *Cardium striatulum*, while below occur *Ammonites serratus* and *Exogyra virgula*. In Lincolnshire the upper beds are also well developed, containing the same species with the addition of *Lingula ovalis*, and *Avicula velicata*, *Belemnoteuthis*, *Gervillia tetragona*, and *Ostrea gibbosa*.

Lower Kimmeridge.—The Lower Kimmeridge consists of thick beds of clay, offering little lithological distinction except in the district of the Coral Rag. The lower group occurs in Lincolnshire and Dorsetshire, the beds in both areas being of the same age.[1]

Lower Kimmeridge Fauna.—At Market Rasen, the Lower Kimmeridge beds exhibit a large and remarkable series of fossils, comprising no less than 32 genera and 46 species. The chief Ammonites are—*A. decipiens*, *A. mutabilis*, *A. rotundus*, *A. cymodoce*, *A. Berryeri*, and *A. serratus*. The chief Gasteropoda are *Cerithium forticasotatum* and *Rostellaria rasenensis*, with *Arca reticulata*, *Astarte supracorallina*, *Pholadidea abbreviata*, *Ostrea deltoidea*, *Pecten Thurmanni*, &c.

The great mass of the Kimmeridge Clay of the "*inland counties*" belongs to the lower division, and the beds agree with the lower beds of Lincolnshire, although doubtfully at Swindon and at Hartwell. The following species, amongst others, occur in the Kimmeridge beds at Swindon: *Ammonites biplex*, *Cerithium multiplicatum*, *Trigonia incurva*, *Astarte supracorallina*, *Nucula menkii*, *Lucina substriata*, *Cardium striatulum*, *Thracia depressa*, *Perna mytiloides*, *Modiola palida*, *Exogyra virgula*, and *E. nana*. These are probably Upper Kimmeridgian.

The beds between Wootton Bassett and Swindon exhibit the same fossils with additional species:[2] *Mactromya rugosa*, *Pecten grenieri*, *Arca mosensis*, *Astarte Michaudiana*, *Ammonites decipiens*.

Passage-Beds.—The Kimmeridge Clay of Weymouth passes downwards with a series of sandy and stratified beds (described by Mr. Blake as "Passage-beds"), containing a peculiar suite of fossils, and believed by Dr. Waagen to be equivalent to a portion of the "*Calcaires à Trigonies*" of the Cap de la Hêve of Dollfus, who includes part of them in the Upper Calcareous Grit.[3] They are the Kimmeridge Grits of Damon at Weymouth and the interior.[4]

[1] Prof. Judd believes that the Horncastle beds belong to the Middle Kimmeridge; they contain a well-marked fauna—*Ammonites mutabilis*, *Rostellaria mosensis*, *Cerithium cribrum*, *Cardium striatulum*, *Lingula ovalis*, *Avicula ædilignensis*, *Astarte supra-corallina*, *Corbula Deshayesii*, *Arca reticulata*, *Homomya compressa*, *Thracia depressa*, and *Serpula intestinalis*.

[2] The remains of the great Deinosaur "*Omosaurus*" (*O. armatus*, Owen) were obtained from the railway cutting here.

[3] See Rev. J. F. Blake, Q. Jour. Geol. Soc., vol. xxxi. p. 213.

[4] Geol. of Weymouth.

Fauna of the Passage-Beds at Weymouth.—These Passage-beds at Weymouth are about 20 feet thick, and in places very fossiliferous. In the uppermost beds, "*Green sandy beds*" (Trigonia-beds of collectors), and the oyster band, organic remains abound; 40 genera and 56 species are crowded in this one sandy bed not more than 3 feet in thickness. Numerically, they are *Ammonites*, $\frac{1}{2}$; *Belemnites*, $\frac{1}{2}$; *Gasteropoda*, $\frac{1}{8}$; *Dimyaria*, $\frac{1}{4}\frac{1}{4}$; *Monomyaria*, $\frac{1}{12}$; *Brachiopoda*, $\frac{1}{8}$; *Annelida*, $\frac{1}{8}$; one crustacean, *Eryma Babeani*; *Cidaris florigemma*, and the Coral *Trochocyathus*. The oyster-bed before named contains an assemblage of fossils, many of which differ from the highest bed (or No. 1), the additional forms being *Mactra tenuissima*, *Pecten lens*, *P. arcuatus*, *Avicula œdilignensis*, *Modiola subæquiplicata*, and *Cidaris Smithii*.

There is considerable faunal community between the Oxford and Kimmeridge Clays—*e.g.*, *Ostrea dilatata* and *Serpula intestinalis* occurring in both; *Avicula Dorsetensis*, of the Ringstead Kimmeridge Clay, is also in the Oxford Clay of Lincolnshire, and *Ammonites cordatus* in the Kimmeridge of Yorkshire. *Thracia depressa* is common to both formations.[1]

The Upper Kimmeridge is fairly comparable to the lower portion of the *Virgulian* group of foreign authors. It consists of bituminous shales, slabs, and cement stones, with interstratified clays. All the great Saurian remains (*Pliosauria*, &c.) from near Kimmeridge belong to this part of the series. "It is of considerable thickness in Dorsetshire and Lincolnshire, but is inconsiderable or absent in the inland counties. . . . No distinct fauna comparable to that of the Middle Kimmeridge or *Pterocerian* group in France has yet been discovered in England, though several of the less peculiar fossils of that group are found associated with Lower Kimmeridge forms."[2]

"The Lower Kimmeridge is chiefly composed of sandy clay but little stratified, and contains numerous calcareous doggers. It is typically developed in Lancashire, where it shows well-marked regions; the whole represents the *Astartian group* of foreign geologists."[3]

The total thickness of this section cannot well be ascertained. It has been estimated at from 300 to 500 feet in Ringstead Bay, and cannot be much less than 400 feet in Lincolnshire.

"The Kimmeridge Passage-beds are developed only in the presence of the Coral Rag, whose fossils ascend into them, but not to any appreciable extent above."[4]

We have seen that the Kimmeridge Clay in England is divisible into two sections—an upper and a lower; and when preceded by the Coral Rag, it possesses at the base a series of beds, which may be called the Kimmeridge Passage-beds, rich in fossils, many peculiar.

[1] The lowest bed (No. 12) passes down to the Ironstone band of the Coral Rag (*Vide* Blake, *loc. cit.*, p. 214).

[2] See Damon, "Handbook to the Geology of Weymouth and the Isle of Portland," for much information relative to the Kimmeridge Clay, pp. 53–70.

[3] *Vide* Q. Jour. Geol. Soc., vol. xxxi. pp. 216–17. The Rev. J. F. Blake.

[4] See also the classification of the Kimmeridge beds, by Dr. Waagen: "Versuch einer allgemeinen Classification der Schichten des Oberen Jura," München, 1875.

Palæontology of the Kimmeridge Clay.

Plantæ.—*Pinites depressus* is the only plant known in the Kimmeridge Clay. This constitutes the entire known flora of the Upper Jurassic rocks in Britain.

Protozoa.—Seven genera and 13 species of Foraminifera occur; they are *Bolivina*, 1 species; *Dentalina*, 3; *Glandulina*, 1; *Lagena*, 2; *Planularia*, 1; *Polymorphina*, 3; and *Pulvinulina*, 2 species. From the Upper Lias to the Kellaways Rock inclusive, there is scarcely any evidence of Foraminifera in the British Jurassic rocks.

Cœlenterata.—As in the Callovian and Oxfordian strata, so in the Kimmeridgian, no remains whatever of Actinozoa have occurred, notwithstanding all the research into these three horizons.

Echinodermata.—*Cidaris baculifera*, *C. boloniensis*, *C. spinosus*, *Hemipedina Cunningtoni*, *H. corallina*, *H. Morrisii*, and *Pentacrinus sigmaringensis*, compose the Echinodermal fauna of the Kimmeridge Clay.

Annelida.—Only *Serpula Royeri*, *S. variabilis*, and *Vermicularia contorta* are known.

Crustacea.—*Callianassa isochela*, *Eryma Babeani*, *Glyphea leptomana*, *G. Stricklandi*, *Mechocheirus Peytoni*, *Pollicipes Hausmanni*, and *Scalpellum reticulatum* constitute the crustacean fauna.

Polyzoa.—None.

Brachiopoda.—Individuals of the non-articulate forms *Lingula* and *Discina* are abundant. *Discina Humphresiana* and *Lingula ovalis* also occur in the Corallian series. The *Rhynchonellæ* are *R. Sutherlandi*, *R. subvariabilis*, *R. inconstans*, and *R. pinguis*. The remainder are *Terebratula Gesneri* and *T. Joassi*.

Pelecypoda (Lamellibranchiata) *Monomyaria.*—Eleven genera and 42 described species are known. No less than 23 species of this group are confined to the Kimmeridge Beds. Six pass to the Portland; they are *Exogyra nana*, *E. spiralis*, *Ostrea deltoidea? O. expansa*, *O. solitaria*, and *Perna mytiloides*.

Dimyaria.—Twenty-six genera and 58 species; 36 of these 58 are confined to this horizon. Twelve species are common to the Corallian beds below; these passage or uniting species are *Astarte ovata*, *Cardium striatulum*, *Goniomya minuta*, *G. v-scripta*, *Homomya gracilis*, *Modiola bipartita*, *M. pallida*, *Myacites oblatus*, *Opis corallina*, *Pholadomya paucicosta*, *Thracia depressa*, *Trigonia clavellata*, and *Mactra tenuissima*. So far as we know, 7 genera and 10 species pass to the Portland Beds. The connecting species of the Kimmeridgian and Portlandian rocks are *Cardium morinicum*, *Modiola pallida*, *Nucula obliquata*, *Pholadomya rustica*, *Pleuromya æquistriata*, *Thracia depressa*, *Trigonia incurva*, *T. Manselli*, *T. muricata*, and *T. Pellati*.

Gasteropoda.—The distinctiveness of this class in the Corallian beds is equally complete and definite; 23 species occur, and with two exceptions, *Pleurotomaria reticulata* and *Turritella minuta*, all are restricted. *Pleurotomaria reticulata* occurs in the Corallian beds, and the *Turritella* passes to the Portland. This concise history of the

Kimmeridge Gasteropoda, like that of the Corallian, has scarcely any parallel in any other member of the British strata.

Cephalopoda. *Ammonites.*—Thirty-one species occur in, and 22 are strictly confined to, the Kimmeridgian strata. Of the remaining 9 species only 4 pass to the Portlandian beds; they are *Am. triplicatus*, *Am. triplex*, *Am. biplex*, and *Am. hector*. The importance of the Ammonites, stratigraphically as well as zoologically, necessitates our naming those species that are essentially of this age; and as all the Jurassic forms become extinct with the close of the Portland, this may be of consequence. The 22 Kimmeridge species are *Am. accipitris*, *Am. autissiodorensis*, *Am. Berryeri*, *Am. Beaugrandi*, *Am. calisto*, *Am. cœcilia*, *Am. cymodoce*, *Am. decipiens*, *Am. eudoxus*, *Am. eumelus*, *Am. eupalus*, *Am. flexuosus*, *Am. Kapffi*, *Am. Lallerianus*, *Am. mutabalis*, *Am. orthocera*, *Am. polyplocus*, *Am. pseudo-mutabalis*, *Am. rotundus*, *Am. superstes*, *Am. Thurmanni*, and *Am. yo*. The genera *Perisphinctes*, *Aspidoceras*, *Cosmoceras*, &c. are represented amongst this series of Ammonites.

Nautili.—None known.

Belemnites.—Eight species, and 7 of them are confined to the Kimmeridge.

Belemnites abbreviatus allies the Kimmeridge fauna with the Corallian and Oxford below. The Jurassic Dibranchiata die out with the close of the Kimmeridge. These last Jurassic forms are *Bel. contortus*, *Bel. excentricus*, *Bel. explanatus*, *Bel. lateralis*, *Bel. nitidus*, *Bel. Souichii*, and *Bel. Trostyanus*. No species is known in the Portland beds of Britain or France.

Teuthidæ.—*Coccoteuthis latipinnis*, Owen. This genus, combining some of the characters of the *Sepia* with those of *Loligo*, *Sepioteuthis*, &c., is extremely rare, and is only known in the Upper Kimmeridge beds.

Pisces.—Every species in the Kimmeridge Clay is confined to it. There are 11 genera and 14 species. These 11 genera represent no less than 5 families; the Sauroidei, through *Ditaxiodus* and *Thlattodus*; the Cestraciontidæ, through *Asteracanthus* and *Strophodus*; the Pycnodontidæ, through *Gyrodus*, *Gyronchus*, *Pycnodus*, and *Sphærodus*; the Placoidei, through *Hybodus* and *Sphenonchus*; and the Cœlacanthini, through *Macropoma*.

Reptilia.—The largest number of Reptilia, either in genera or species, known in the Secondary rocks of Britain, occurs in the Kimmeridge Clay. Six orders are represented, viz., the Chelonia, Crocodilia, Ichthyopterygia, Sauropterygia, Pterosauria, and Deinosauria; these 6 orders contain the following 17 genera and 45 species:—

		Species.
Crocodolia	Bothriospondylus	1
	Dakosaurus	3
	Steneosaurus	5
	Teleosaurus	2
Chelonia	Enaliochelys	1
	Pelobatochelys	1
Ichthyopterygia	Ichthyosaurus	6
	Ophthalmosaurus	1
Sauropterygia	Plesiosaurus	12
	Pliosaurus	5

		Species.
	Brought over .	37
Pterosauria . . . (Ornithosauria, *Seeley*)	Pterodactylus . . .	2
Deinosauria . . .	Cetiosaurus . . .	1
	Cryptosaurus . . .	1
	Gigantosaurus . . .	1
	Iguanodon . . .	1
	Megalosaurus . . .	1
	Omosaurus . . .	1
		45

Of the above 45 species only 5 occur in other horizons, or 40 are confined to the Kimmeridge beds. The 5 are *Ichthyosaurus dilatatus*, *I. thyreospondylus*, *Megalosaurus Bucklandi*, *Plesiosaurus plicatus*, and *P. trochanterius*, which are also Oxford Clay forms, the only species in the intermediate Corallian being *Megalosaurus Bucklandi*; which only Reptilian genus uniting the Kimmeridge and Portland beds.

TABLE LXXI.—*Range of the Reptilia through the Jurassic Rocks.*

Orders.	Lower Lias.	Middle Lias.	Upper Lias.	Inferior Oolite.	Fuller's Earth.	Great Oolite.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Corallian.	Kimmeridge Clay.	Portlandian.	Total Genera and Species.
Chelonia . . .	...	...	...	...	...	2	...	...	...	...	1	2	...	6
Crocodilia . . .	...	...	4	...	...	5	2	...	...	1	...	11	1	24
Ichthyopterygia . .	1/1	1/1	1/1	...	...	2/2	...	...	...	1/1	...	2/2	...	7/7
Sauropterygia . .	1/3	1/1	1/1	...	...	1/1	...	...	...	1/1	1/1	1/7	1/2	1/15
Pterosauria . . .	1/1	...	...	...	...	1/1	...	...	...	...	...	1/2	...	2/5
Lacertilia . . .	...	...	...	...	...	1/1	...	...	...	...	...	...	...	1/1
Deinosauria . . .	1/1	...	...	1/1	...	2/3	1/1	1/1	...	2/2	1/1	2/6	2/2	18/18

The above Table (LXXI.) shows the genera and species in the 7 orders of Reptilia and their range through the 13 divisions of the Jurassic rocks, also the total numbers of genera and species in each of the horizons, ranging from the Lower Lias to the Portland.

Mammalia.—None known.

Portland Oolite.

Range.—The Portland rocks in England have a very limited geographical range; they appear in Dorsetshire, Wiltshire, Buckinghamshire, and Oxfordshire—in the three last-named counties occurring only in patches, though doubtless they were once continuous. They are not again observed north of Oxford until we reach Speeton Bay or Filey, in Yorkshire, where at low water, south of Filey Brigg, and at certain states of the tide, they are laid bare.[1] The rock occurs

[1] The Rev. J. F. Blake, in his "Memoir on the Portland Rocks of England" (Q. Jour. Geol. Soc., vol. xxxvi.), has given comparative sections of the Portland series from 9 localities, between Portland and North Buckinghamshire.

in its normal condition in the Island of Portland, where typical and detailed sections can be seen, resting upon the dark clays of the Kimmeridgian series.

A.—The Island of Portland.—The line of demarcation between the Portland and succeeding Purbeck is clear and constant, consisting, in the Island of Portland, of a layer of clay, resting upon an uneven surface of the Portland rocks.[1] Fourteen distinct well-defined beds or divisions in the Portland oolite of Portland have been determined. They are shown in the following table:—

TABLE LXXII.—*Sequence of Beds in the Portland Oolite.*

Portland Stone Oolite.	Building beds	No. 1. The "Roach bed."—Shell limestone, with *Cerithium Portlandicum*, *Sowerbya Dukei*, and *Buccinum naticoides*, *Trigonia gibbosa*, *Lucina Portlandica*, *Pecten lamellosus*, *Ostrea expansa*, and *Natica elegans*. *Buccinum naticoides*, *Sowerbia*, sp.[2]
		No. 2. The "Whit bed."—The true *Ammonites giganteus* is peculiar to this bed.
	Flinty beds.	Nos. 3–9 are the "flinty series." No. 3 is the "curf." *Ostrea solitaria* is the dominant species here.
		No. 4. The "Base bed"—resembles the "Whit bed" in appearance, but is distinguished from it by the presence of irregular bands of flint. This and No. 3 are the home of the rare "*Isastræa oblonga*," and its perforating *Lithodomi*.
		No. 5. The upper block is full of *Trigonia gibbosa*, and may be named the "Trigonia bed." This bed, through varying or changeable thickness, may have been deposited on an uneven surface. In one place it is lying on No. 6, and not more than from 4 to 6 feet thick, whilst in another it cuts No. 8, and is nearly 20 feet thick. It resembles the "Roach," but *Perna mytiloides* takes the place of *Cerithium Portlandicum*.
		No. 6. Three feet in thickness. The upper part solid flint.
		No. 7. Lower part full of *Serpula gordialis*, and containing abundance of *Ostrea multiformis*. Lower part more free from flints. Six feet thick.
		No. 8 constitutes the main mass of the flinty series; the layers are irregular, false bedded, and more chalky than the beds above No. 6. Fucoid markings occur on the blocks. *Ammonites boloniensis* (*de Loriol*), *Trigonia gibbosa* and *T. incurva*, and *Perna*, sp.
		No. 9. Shell bed—abounds in small oysters, *Serpulæ* and *Trigoniæ*. This bed supplies us with the fauna of the Flinty series. The chief are *Ammonites pseudogigas*, *A. triplex*, *Pleurotomaria rugata* and *P. Rozeti*, *Cardium dissimile*, *Cyprina elongata*, *Lima rustica*, *Pecten lamellosus*, *Trigonia gibbosa*, *T. incurva*, and *Pleuromya tellina*. Thickness nearly 8 feet.

[These 9 beds constitute the *Portland stone*, and they appear to form two subdivisions, distinguished by their stratigraphy, lithology, and palæontology. The upper, or beds Nos. 1 and 2, are the Building-stones, and Nos. 3 to 9 the "Flint beds." The thickness of the Building series is about 12 feet, that of the flinty group about 68 feet, probably divided into two slightly unconformable masses.]

[1] The lower Purbeck beds are known as the "*cap*" and the "*skull cap*." They are botryoidal limestones or indurated calcareous tuffs, possibly derived from the denudation of the Portland rocks. The dividing clay layer contains Portland flints; evidence of derivation.

[2] See "Handbook to the Geology of Weymouth and the Island of Portland, Damon," pp. 71–88, for much information relative to the Portland rocks of Weymouth, &c.

TABLE LXXII. (*continued*).

PORTLAND SAND. Marly series.

No. 10. A blue marl, 12 to 14 feet thick, no fossils.
No. 11. Marl and sand, liver-coloured, with isolated nodules and thick continuous bands of a sandy cement-stone. The cement-stone fossils are *Mytilus autissiodorensis, Pecten solidus, Cyprina implicata.*[1]
No. 12. The Exogyra beds—*E. bruntrutana*, to the exclusion of all other shells, forms a mass of rock 7 feet thick.
No. 13. Yellow sandy beds—with *Cyprina implicata* and *Arca.*
No. 14. Sandy marl, gradually changing into true Kimmeridge Clay. Thirty feet exposed. The important species in this bed for correlation are *Ammonites biplex, Natica incisa*? *Lima boloniensis*—special at Boulogne—*Pecten Morini, Avicula octavia, Trigonia incurva, T. muricata, T. Pellati, Pleuromya tellina, Rhynchonella portlandica*, and *Discina Humphresiana.*[2]

B.—The St. Alban's Head and Kimmeridge Section.—This is so fully described and compared with the type at Portland,[3] by Mr. Blake, that further notice is needless. These two sections convey the entire history of the Portlandian rocks.

The St. Alban's Head section comprises 16 beds, and exhibits 357 feet of strata. Comparison made by Mr. Blake, with the Boulogne beds, shows the episodal character of the French deposit. The upper part of the French "Middle Portlandian" is our Portland sand; their beds measuring only about 60 feet, not one-half the thickness of the corresponding beds at St. Alban's (*vide* Blake, *loc. cit.*)

C.—Upway.—Only 3 beds are shown here; they are, however, instructive.

No. 1, the uppermost, is 3 feet 6 inches thick, and full of *Trigoniæ*, but contains no *Cerithium portlandicum.*

No. 2, the second bed, is chalky and flinty; the flints are in large masses; thickness 40 feet.

No. 3.—This corresponds to the clay at Portland which underlies the flinty series, and to which No. 2 above corresponds. The ordinary fossils are those of the flinty series, *Cardium dissimile, Pecten lamellosus, Trigonia gibbosa, Lucina portlandica*, and *Ammonites boloniensis.*

D.—The Vale of Wardour.—This important locality and its group of rocks require careful study. The researches of Dr. Fitton long ago made this classic ground.[4] Eleven well-marked beds or divisions occur in the Vale of Wardour.

No. 1. Fine-grained brown oolite—lower part yields *Cerithium portlandicum.*
No. 2. Finely oolitic at the upper part with *Cerithium portlandicum.*
No. 3. White chalk rock, like that of Upway. Portland fossils abundant—viz., *Pecten lamellosus, Cardium dissimile, Lucina portlandica, Pleuromya tellina, Ostrea expansa*, and *Trigoniæ.*

[1] These three species occupy the same horizon elsewhere in England and at Boulogne.

[2] Throughout the Portland sand series (Nos. 10–14), Professor Blake does not detect either glauconite or pebbles, and the fauna, though connected with the Portland series, is yet, according to him, more allied to the upper part of the Kimmeridgian beds.

[3] Q. J. Geol. Soc., vol. xxxvi. pp. 190–8.

[4] On the strata between the Chalk and the Kimmeridge Clay in the S.E. of England, *vide* Geol. Trans., vol. iv. p. 103.

No. 4. The most fossiliferous bed in the Portland series of the Vale of Wardour, containing *Astarte rugosa*, *Cerithium concavum*, *C. Bouchardianum*, *Nerita transversa*, and *Neritoma sinuosa*.
No. 5. Trigonia-bed. *T. gibbosa*.
No. 6. The chief beds of the Quarries. A fine limestone. Thick bands, containing *Isastræa oblonga*, *Ammo. boloniensis*, and *Am. biplex*.
No. 7. This is the last bed of the Portland Oolite above the sands.
No. 8. Yellow impure sand. Marly at the base. No fossils.
No. 9. Impure calcareous bed, with grains of Glauconite or Lydian stone. 3 feet 6 inches, and rich in fossils—*Trigonia Pellati*, *T. variegata*, *T. concentrica*, *T. Micheloti*, *Mytilus jurensis*, *Perna Bouchardi*, *Pecten concentricus*, *Astarte supra-corallina*, and *Exogyra bruntrutana*.
No. 10. Harder bed of the same character, 3 feet 6 inches, with *Trigonia Pellati*, *Ostræa bruntrutana*.
No. 11. Yellowish-grey calcareous stone. No fossils.

E.—Swindon.—The sections shown in the great Quarries at Swindon are the most extensive out of the islands of Portland and Purbeck, and the relation of the Purbeck strata to the Portland is nowhere else so clearly to be seen or studied. Nowhere can the unconformability be so plainly demonstrated.[1] The true Portland rocks are clearly seen below the Purbeck at the north-east portion of the chief exposure. In the general section at Swindon six divisions of the Portlandian beds can be determined.

No. 1. This bed is of little value in classification.
No. 2. The beds comprising this division are about 25 feet in thickness, composed of calcareous sands, and are the true equivalents of the Tisbury stone and the lower portion of the flinty series at Portland. The chief fossils are *Ostrea solitaria*, *Lima rustica*, *Mytilus unguiculatus*, *Cyprina pulchella*, *Corbula dammariensis*, and *Pleuromya tellina*.
No. 3. *The Trigonia beds.* The limestones in this series are more highly developed than the corresponding beds at Tisbury and Portland. They are visible at the deepest part of the Great Quarry, the 7 feet exposed being full of *Trigonia gibbosa*. *At Coate* lower beds are seen, containing the Glauconite and Lydian stone beds, and furnish evidence of wanting or unseen beds in the Swindon quarry. This well-known section, north of the road to Coate, is rich in fossil remains, especially the "Trigonia beds."

Fauna of the Coate Beds.—The fauna of the Coate beds comprises the following characteristic species:—*Ammonites boloniensis*, *A. pectinatus*, *A. Boisdini*, *Pleurotomaria rugosa*, *Natica elegans*, *Trigonia gibbosa*, *T. Voltzii*, *T. incurva* and *T. Carrei*, *Cyprina elongata*, *Cypricardia costifera*, *Anisocardia pulchella*, *Cardium dissimile*, *Lucina portlandica*, *Pleuromya tellina*, *Thracia tenera*, *Mytilus unguiculatus*, *M. boloniensis*, *M. pernoides*, *Lima rustica*, *L. ornata*, and *Pecten lamellosus*.

No. 4. Below the limestones at Swindon there occurs a well-defined bed of clay, about 20 feet thick, which has yielded the following fossils, demonstrating that they belong to the Portland sands. They are *Trigonia incurva*, *Perna Bouchardi*, *Mytilus autissiodorensis*, *Corbula dammariensis*, *Arca Beaugrandi*, and *Cyprina elongata*.[2] A clay of similar character precedes the shelly limestones of the Isle of Portland.

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[1] For complete description of these extensive deposits by the Rev. J. F. Blake, M.A., *vide* Q. J. G. S., vol. xxxvi. pp. 203-213. Also consult the paper by the Rev. P. B. Brodie, Q. J. Geol. Soc., vol. iii. p. 53.

[2] We are careful to give these species through the several well-determined beds of this and other formations; they are essential to all students.

No. 5. The upper part of this bed is a sandy Glauconitic clay full of fossils, and the lower "a regular lumachelle" of *Exogyra bruntrutana*. The fauna of this thin bed (the Portland sand) contains no less than 26 genera and 37 species. This fauna is distinguished from that of the Portland rock; the typical and prevailing Trigonia (*T. Gibbosa*) and Cardium (*C. dissimile*) are younger in time. Many of the species are characteristic of the so-called Middle Portland of Boulogne—*Sowerbya longior*, *Myoconcha Portlandica*, *Cyprina Swindonensis*, and *Trigonia Swindonensis*.

No. 6. Incoherent yellow-grey or white sands, containing enormous *doggers*, some occurring at the top as a calc. grit, with *Trigonia Pellati* and *P. voltzii*. These are succeeded by non-retentive argillaceous sandy beds, resting on sandy clays, crowded with Kimmeridge Clay fossils. The thickness of the Swindon Portland series may be about 50 feet.

F.—Oxfordshire.—Nowhere in Oxfordshire are the Portland Rocks seen in one continuous section; their value consists in affording means for showing continuity and connection between the sections exhibited in Wiltshire and Buckinghamshire. At Great Hazeley and Great Milton, the upper parts of the Portland beds are widely spread out.[1] Like the series at Swindon, six groupings may be determined. The base of all the quarries at the above places is a yellow non-glauconitic sand some 10 or 15 feet thick. The uppermost seam is a solid bed of Gritty Limestone with Pernæ. These upper Limestones contain the chief fossil remains—*Cerithium Portlandicum*, *Trigonia incurva*, *Lima rustica*, *Pecten lamellosus*, *Ostrea expansa*, and *Pleuromya tellina*.

The beds comprising the fine section at Shotover near Oxford—through the known succession and correlation with these, Hazeley, Great Milton, Coddesdon, and Garsington beds—are now placed in their true position. Dr. Fitton briefly described them.[2] Prof. Phillips in his able book[3] has written the history of the period, through the Shotover and Headington deposits; and Saemann[4] has shown, through *Trigonia gibbosa* and the accumulation of fossils at the upper part, the position of Phillips' fossils, which corresponds to the bed No. 5 of Mr. Blake in his "comparative sections" (fig. 7).[5] The non-Glauconitic, non-fossiliferous sands with huge *Doggers*, as at Swindon, complete the downward section at Shotover.

G.—Buckinghamshire.—The characteristic feature of the Buckinghamshire Portland rocks is their greater development of limestones, and, consequently, richer fauna—Dr. Fitton (*loc. cit.*), L. Saemann (succession at Hartwell, De Loriol and Pellat., *loc. cit.* t. 1, f. 7, and p. 189), the Rev. P. B. Brodie[6]—and figures 8 and 9 in the comparative sections in Blake's memoir (*loc. cit.*), show the succession for North and South Bucks, with local differences in deposition or sedimentation.

[1] Dr. Fitton describes the Hazeley section in his exhaustive memoir ("Strata below the Chalk"), Trans. Geol. Soc., vol. iv. p. 276.

[2] *Loc. cit.*, p. 278.

[3] "Geol. of Oxford and Valley of the Thames," pp. 324–391.

[4] De Loriol and Pellat. (Mém. Ac. Soc. Phys. et Hist. Nat., Genève, tom. xix. p. 192, t. 1.)

[5] "Portland Rocks of England." Q. J. Geol. Soc., vol. xxxvi., facing p. 236.

[6] Section at Brill in Mono., "Brit. Fossil Echinodermata," Pal. Soc., 1859, p. 354. See also Fitton, *loc. cit.*, p. 289, 1 for the Brill sections.

1. The uppermost Portland Rocks are here a compacted shell-brash; *Mytilus pallidus*, *Trigonia gibbosa*, *T. Pellati*, and small *Lithodomi* are the chief fossils.

2. Possesses an extensive fauna, shown at the base of the thick limestone at Brill and Crendon, &c.; 29 genera and 44 species have been collected from it. The most characteristic shells here, as in the true Portlandian of Boulogne, are *Natica ceres*, *Cerithium Portlandicum*, *Astarte rugosa*, and *Lucina Portlandica*.

3. Highly fossiliferous rubbly limestones. Dr. Fitton notices this limestone in his Quainton section as the "Middle Rock and Rubble-stone abounding in Fossils."[1] Its character is best observed at Coney Hill, where about 8 feet are exposed. At Brill a rich fauna occurs, numerically comprising 17 genera and 34 species. Of these 34 species the *Trigoniæ* are important, 7 out of the 26 species of bivalves belonging to that genus. The Ammonites here are important for correlation, especially *A. pectinatus*. The remaining forms are *Am. boloniensis*, *Am. pseudogigas*, *Am. triplex*, and *Am. biplex*. The whole thickness of the Portland rocks in this area averages between 60 and 70 feet. Mr. Blake gives two interpretations relative to the Buckinghamshire and Oxfordshire Portland rocks,—*first*, that we have here *thin* representatives of all the Portland deposits which elsewhere reach a far greater thickness; *secondly*, that we may match these beds with some part of those at Swindon.

Fauna.—The following species are common to the limestones of Buckinghamshire and the *Trigonia* beds of Swindon and Bourton:—*Ammonites pectinatus*, *Natica elegans*, *Trigonia Voltzii*, *Cyprina elongata*, *Cypricardia costifera*, *Anisocardia pulchella*, *Pleuromya tellina*, *Thracia tenera*, *Mytilus unguiculatus*, *Mytilus boloniensis*, and *Echinobrissus Brodiei*.

At Swindon the relations of the Purbeck to the Portland rocks are remarkable, the Portland being worn or carved out in hollows, in which are rolled masses, evidencing a land surface and rapid changes. The Portland sands occur below this, and are extremely fossiliferous and glauconitic. Huge doggers occur in the lower part.[2]

H.—Yorkshire.—The uppermost Jurassic beds in Yorkshire are only seen in Filey Bay; they are but slightly exposed, and that only occasionally at very low water. The presence of the Portland beds in this area may be expected when we consider the development of the Kimmeridge Clay in the Vale of Pickering, the eastern portion of which, although drift-covered, constitutes much of the Bay of Filey. This highest Zone in the Jurassic series Mr. Leckenby had referred to the Portlandian. It consists of three divisions,—the uppermost being a bed of phosphatic nodules (coprolite-bed), seen on the shore opposite Speeton Gap, and near Hunmanby Gap. The fossils of this exposure

[1] Fitton, *loc. cit.*, p. 290.

[2] The author of "The Portland Rocks of England" closes his paper (*loc. cit.*) with a table showing the distribution of all the Portland species through 13 localities. the whole fauna being 63 genera and 128 species, illustrating 11 classes, 5 of which are unrepresented in the Portlandian series.

are *Ammonites gigas*, *A. Gravesianus*, *A. rotundus*, *Lucina Portlandica*, *Lithodomus*, and *Arca*, with remains of Saurians.[1] The lowest portion of the Portland beds at Speeton consist of "dark-coloured clays with stony bands." They are exposed on the shore at low-water mark after a long prevalence of south-westerly gales. The fossils from these beds are Ammonites of the group Coronarii—*A. gigas*, *A. Gravesianus*, *A. Ireus*, *A. giganteus*, and *A. rotundus*, Saurian and fish remains, *Lucina Portlandica*, and crypts of Lithodomi, &c.

Nowhere between Oxford and Brill and Speeton are the Portland rocks again visible, although the Kimmeridge Clay of Lincolnshire would lead us to anticipate their presence in the more highly developed Jurassic series across the Humber.

TABLE LXXIII.—*Showing the Distribution of the Jurassic Rocks over four of the Chief Areas in England.*

S. of England.	N. Oxfordshire and S. Northamptonshire.	N. Northamptonshire and Lincolnshire.	Yorkshire.
Purbeck beds.	None.	None.	None.
Portland ,,	None.	None.	None.
Kimmeridge Clay.	Kimmeridge Clay.	Kimmeridge Clay.	Kimmeridge Clay.
Corallian.	Corallian.	Corallian.	Corallian Calc. Grit.
Oxford Clay.	Oxford Clay.	Oxford Clay.	Oxford Clay.
Kellaways Rock.	None.	Kellaways Rock.	Kellaways Rock.
Cornbrash.	Cornbrash.	Cornbrash.	Cornbrash.
Forest marble and Bradford clay.	None.	Great Oolite clays.	None.
Great Oolite.	Great Oolite (Up. part).	Great Oolite.	None.
Fuller's Earth.	None.	Upper Estuarine series.	None.
Inferior Oolite Limestone.	Northampton Sand (equivalent of the Inferior Oolite).	Inferior Oolite, Northampton Sand, &c.	Sandstone shales, coals, &c. Micaceous and Ferruginous sandstone: Dogger.

Lias.

Ranges through England from N.E. to S.W.

- Upper Lias sands in S. and W. of England.
- Upper Lias clay ,, ,, ,, and Yorkshire, &c., &c.
- Middle Lias: Sandy beds / marlstone. — Ironstones in places, chiefly in the upper part, Cleveland, &c., Yorkshire.
- Lower Lias clays and shales. } From Dorsetshire to Yorkshire.
- ,, ,, Limestones and shales, and Iron Ores in N. Lincolnshire. }

The above table shows the persistency of the three great Clay groups, the Lias Clay, the Oxford Clay, and the Kimmeridge Clay, throughout England.

[1] Many years since there was found near "New Closes Cliff" a nearly perfect skeleton of a *Plesiosaurus*, a portion of which is (or was) in the possession of Lord Londesborough.

Portlandian Fauna.

Plantæ.—Fragments of wood only.

Protozoa.—None.

Cœlenterata.—*Isastræa oblonga* is the only Portland species; it is also the only coral in the Calcareous rocks of Britain whose skeleton or corallum is now entirely siliceous.

Echinodermata.—*Echinobrissus Brodiei*, *Hemicidaris Brillensis*, and *H. Davidsoni* are all that are known in the Portlandian beds.

Annelida.—*Serpula* is the only genus, and is represented by 4 species—*S. gordialis*, *S. quinquangularis*, *S. triserrata*, and *S. variabilis*.

Crustacea.—The Entomostraca only are represented by *Cythereis interrupta* and *C. Lonsdaleiana*.

Polyzoa.—None known.

Brachiopoda.—*Waldheimia Boloniensis*, *Terebratula rex*, and *Rhynchonella*, sp.

The accompanying Table, LXXIV., exhibits the numerical value and distribution of the whole of the Jurassic Brachiopoda, and the total number of appearances of the species in each genus:—

TABLE LXXIV.—*The Numerical Distribution of the Jurassic Brachiopoda.*

Genera.	Number of species in the Jurassic rocks.	Lower Lias.	Middle Lias.	Upper Lias.	Inferior Oolite.	Fuller's Earth.	Great Oolite.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Coral Rag.	Kimmeridge Clay.	Portland.	Total appearances.
1. Terebratula .	72	4	10	3	31	5	7	4	5	3	2	7	2	1	84
2. Waldheimia .	44	3	13	3	13	4	4	3	8	2	3	6	...	1	63
3. Terebratulina .	4	...	1	1	2	...	1	...	...	...	...	...	...	...	5
4. Thecidium . .	15	5	4	4	9	1	1	...	...	...	...	2	...	...	26
5. Zelania . . .	6	1	...	1	3	...	1	...	...	...	...	1	...	..	7
6. Terebratella .	5	...	1	...	...	...	4	...	...	...	...	..	...	...	5
7. Suessia . . .	1	...	1	...	...	...	...	...	...	...	...	...	...	...	1
8. Spiriferina . .	18	5	12	5	3	...	...	...	...	...	...	...	...	...	25
9. Rhynchonella .	76	9	19	10	23	4	5	3	5	3	2	3	4	1	91
10. Lingula . . .	11	2	3	4	1	...	...	...	...	1	2	1	1	...	15
11. Megerlia . .	2	...	2	...	...	...	...	...	...	...	...	...	...	...	2
12. Leptæna . .	6	...	3	6	...	...	...	...	...	...	...	...	...	...	9
13. Kingena . .	1	...	1	...	...	...	...	...	...	...	...	...	...	...	1
14. Discina . . .	18	3	2	8	3	...	...	...	1	1	1	1	3	...	23
15. Argiope . . .	1	3	...	...	...	...	1	...	...	...	...	...	...	...	4
16. Crania . . .	8	1	2	2	2	...	2	...	...	...	...	...	...	...	9
Total . . .	1/8/8	1/0/0	1/4/4	1/1/1	1/0/0	4/14	9/26	3/10	4/18	5/10	5/10	7/21	4/10	2/2	2/9/10

Pelecypoda (Lamellibranchiata).—*Monomyaria*—9 genera and 19 species are known. Twelve of the 19 first appear, and only occur in

the Portlandian rocks, no species passing to the Purbecks; the remaining 7 species come either from the Corallian or Kimmeridgian beds below, and 6 species actually connect the two formations; they are named in the analysis of the Kimmeridge Monomyaria.

Dimyaria.—Twenty-nine genera and 55 species, 42 of which are strictly Portlandian. Ten species come direct from the Kimmeridge Clay; they are named under the Kimmeridge analysis; the remaining 3 are Corallian. No species pass above the Portland rocks. The genera *Trigonia*, *Lucina*, and *Pholadomya* play an important part in the Upper Jurassic rocks.

Gasteropoda.—As we have seen in the Oxford Clay, the Corallian beds, and the Kimmeridge Clay, so now in the Portland, the species all belong to their own special horizons, *Turritella minuta* being the only form common to the Kimmeridge and Portland out of the 10 genera and 19 species occurring.

Cephalopoda. *Ammonites.*—Eleven species occur, 7 of which are Portlandian only; they are *Am. Boloniensis*, *Am. giganteus*, *Am. gigas*, *Am. Gravesianus*, *Am. ireus*, *Am. pectinatus*, *Am. pseudo-gigas.*

The 4 species uniting the Kimmeridge and Portland beds are *Am. triplex*, *Am. triplicatus*, *Am. hector*, and *Am. biplex;* all the species disappear with the close of the Upper Jurassic Period. The genus *Perisphinctes* is well represented among the Portland Ammonites.

Nautili.
Belemnites. } None known.
Teuthidæ.

TABLE LXXV.—*Showing the Numerical and Stratigraphical Value of the whole of the Jurassic Mollusca.*

Classes.	Lower Lias.	Middle Lias.	Upper Lias.	Inferior Oolite.	Fuller's Earth.	Great Oolite.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Corallian Beds.	Kimmeridge Clay.	Portlandian.
Brachiopoda .	$\frac{10}{36}$	$\frac{11}{14}$	$\frac{11}{17}$	$\frac{10}{36}$	$\frac{4}{14}$	$\frac{9}{36}$	$\frac{3}{10}$	$\frac{4}{10}$	$\frac{5}{10}$	$\frac{5}{10}$	$\frac{7}{21}$	$\frac{4}{10}$	$\frac{3}{3}$
Monomyaria .	$\frac{18}{114}$	$\frac{18}{40}$	$\frac{18}{38}$	$\frac{15}{106}$	$\frac{9}{15}$	$\frac{18}{40}$	$\frac{9}{24}$	$\frac{11}{44}$	$\frac{11}{26}$	$\frac{9}{28}$	$\frac{14}{58}$	$\frac{11}{42}$	$\frac{9}{19}$
Dimyaria . .	$\frac{26}{138}$	$\frac{24}{108}$	$\frac{25}{85}$	$\frac{47}{138}$	$\frac{23}{61}$	$\frac{40}{138}$	$\frac{18}{85}$	$\frac{23}{85}$	$\frac{19}{67}$	$\frac{21}{48}$	$\frac{23}{93}$	$\frac{26}{68}$	$\frac{23}{55}$
Gasteropoda. .	$\frac{11}{136}$	$\frac{27}{138}$	$\frac{13}{85}$	$\frac{41}{140}$	$\frac{1}{1}$	$\frac{40}{147}$	$\frac{13}{23}$	$\frac{20}{23}$	$\frac{13}{13}$	$\frac{13}{17}$	$\frac{21}{67}$	$\frac{13}{13}$	$\frac{13}{19}$
Ammonites . .	$\frac{1}{178}$	$\frac{1}{24}$	$\frac{1}{19}$	$\frac{1}{28}$	$\frac{1}{6}$	$\frac{1}{7}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{11}$	$\frac{1}{48}$	$\frac{1}{11}$	$\frac{1}{31}$	$\frac{1}{11}$
Nautili . . .	$\frac{0}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{0}{8}$	...	$\frac{1}{8}$	...	$\frac{1}{4}$	$\frac{1}{2}$	...	$\frac{1}{4}$		
Belemnites . .	$\frac{1}{31}$	$\frac{1}{37}$	$\frac{1}{34}$	$\frac{1}{18}$	$\frac{1}{3}$	$\frac{1}{3}$	...	...	$\frac{1}{3}$	$\frac{1}{18}$	$\frac{1}{4}$	$\frac{1}{3}$	
Teuthidæ . .	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{2}$	...	...	...	...	...	...	$\frac{2}{2}$	...	$\frac{1}{1}$	
Total . .	$\frac{103}{718}$	$\frac{95}{264}$	$\frac{73}{231}$	$\frac{118}{736}$	$\frac{38}{89}$	$\frac{103}{811}$	$\frac{51}{113}$	$\frac{70}{164}$	$\frac{47}{180}$	$\frac{49}{91}$	$\frac{74}{265}$	$\frac{56}{173}$	$\frac{53}{107}$

Pisces.—*Gyrodus Cuvieri, Hybodus striatus, Ischyodus Egertoni, I. Townshendi,* and *Pycnodus pagoda,* are the 4 genera and 5 species known. *Gyrodus Cuvieri* also occurs in the Coral Rag.

Reptilia.—*Cetiosaurus longus, Megalosaurus Bucklandi, Goniopholis* sp., *Plesiosaurus carinatus, P. Winspitensis,* and *Pliosaurus Portlandicus* are all the Reptilia known. Except *Meg. Bucklandi* all are strictly Portlandian.

TABLE LXXVI.—*Analysis and Distribution of the Portlandian Species.*

From Kimmeridge Clay.	Classes.		Genera.	Species.	
		Plantæ, Amorphozoa, Rhizopoda } None.			
		Cœlenterata	1	1	
		Echinodermata	2	3	
1/1		Annelida	1	4	
		Crustacea	1	2	
		Bryozoa (none).			
		Brachiopoda	3	3	
8/8	35 genera and	Monomyaria	9	19	No Species in any Class passes to higher strata.
10/10	74 species.	Dimyaria	29	55	
		Gasteropoda	10	19	
1/1		Ammonites	1	11	
	Cephalopoda.	Nautili, Belemnites, Teuthidæ } None.			
		Pisces	4	5	
		Reptilia	5	6	
		Mammalia (none).			
11/11			66	128	

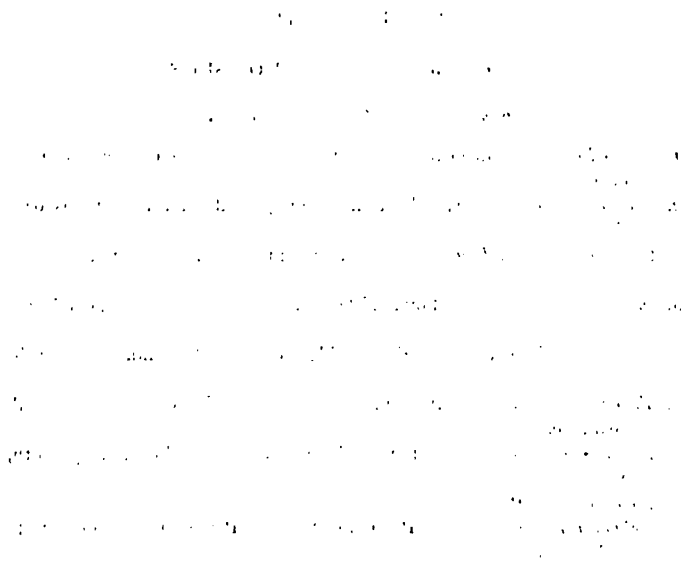


PLATE XXIII.

UPPER JURASSIC FOSSILS.

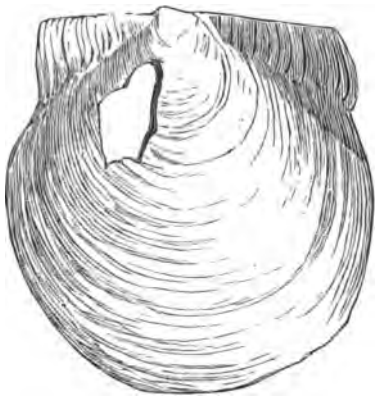
(*Kimmeridgian, Portland, Purbeck.*)

1. *Mantellia nidiformis* (Brong.) Dirt bed, Purbeck beds. Isle of Purbeck.
2. *Pecten lamellosus* (Sow.) Portland Oolite, Wiltshire, Dorset, Oxfordshire, &c.
3. *Cerithium portlandicum* (Sow.) Portland Oolite. Portland, Vale of Wardour.
4. *Ostrea expansa* (Sow.) Portland Oolite. Portland, Swindon, Quainton, &c.
5. *Ostrea deltoidea* (Sow.) Kimmeridge Clay. Portland, Weymouth, and *passim*.
6. *Thracia depressa* (Sow.) Kimmeridge Clay. Weymouth, Hartwell, Brill, &c.
7. *Exogyra virgula* (Def.) Kimmeridge Clay. Aylesbury, Weymouth, &c.
8. *Modiola*, sp. Portland Oolite.
9. *Trigonia gibbosa* (Sow.) Portland Oolite. Portland, Swindon, Vale of Wardour, &c.

PLATE XXIII.

UPPER JURASSIC FOSSILS.

(*Kimmeridgian, Portland, Purbeck*).



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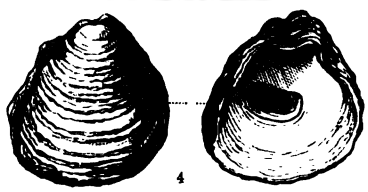

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TABLE LXXVII.—*Number of Genera and Species occurring in the whole of the Jurassic Rocks arranged stratigraphically, or from the Lower Lias to the close of the Portland Oolite.*

Formations.	Genera.	Species.
Lower Lias	249	1106
Middle Lias	137	563
Upper Lias	111	418
Inferior Oolite . . .	221	1008
Fuller's Earth . . .	51	110
Great Oolite	235	827
Forest Marble . . .	65	136
Cornbrash	92	244
Kellaways Rock . . .	52	168
Oxford Clay	73	194
Corallian beds . . .	115	333
Kimmeridge Clay . . .	103	263
Portland Oolite . . .	66	128
	1570	5498

The Table on page 503 shows at once the numerical value of the whole fauna and flora of the British Jurassic rocks; the total number of genera and species known in the several Classes is stated in the two left-hand columns, and all through the Table the numbers of genera and species are expressed in their respective horizons or formations, from the Lower Lias to the Portland Beds. These will be found to agree all through the text when named. This census of the Jurassic species, brought down to 1883, may form the basis of comparison at some future date (perhaps in another twenty years), when it is deemed of sufficient interest to show the increase of the fauna and flora derived from the Lower Secondary Rocks of the British Islands.

Jurassic System.—Summary of Foreign Localities.

Range and Extent.—The Jurassic system so largely developed in England forms a very conspicuous, if not the principal feature in its physical geography, and its extreme ramifications reach the northern, eastern, and western coasts of Scotland and the north-eastern shore of Ireland. But the range of these rocks is still more extensive on the continent of Europe. In France a broad belt of Jurassic rocks borders on the east the Primary rocks of Brittany and La Vendée, and sweeps round the basin of Paris from the coast of Normandy (Calvados), by Falaise, Alençon, Lemans, Saumur, Poitiers, Chateauroux, and Nevers, and through Burgundy, Franche-Comté, and Lorraine, till, along a line from Avesnes to Luxembourg, it abuts against the slate mountains of the Ardennes. From Poitiers the Oolites continue westward to

La Rochelle, southward to Angoulême, Perigueux, Cahors, and the vicinity of Montauban. A little discontinuity here occurs; but the Oolites of Rhodes and the Cevennes mountains are prolonged south-westward to Montpelier, Carcassone, and Foix, along the northern slope of the Pyrenees to Fontarabia, and north-eastward to Montelimart and Grenoble, and so to the Jura, thence south-eastward to Marseilles and Nice, thus uniting into one irregular mass the whole area of the French Oolite. These formations are developed in Spain, and occur on the southern slope of the Pyrenees.

Along the Swiss border of France runs the long calcareous chain of the Jura, and this whole mountain region is a mass of Jurassic rocks. It is therefore received on the Continent as the type of the system; and the terms Jura-kalk, Jura formation, or Jurassic, are equivalent to our Oolitic system. This is connected below the alluvial valley of the Saone with the Oolites of Burgundy. In its continuation northward, the Jura ranges pass in a broad belt through Wurtemberg, Bavaria, and Franconia, and reach the Maine as it issues from the Bohemian mountains.

The Jura is also connected, by crossing the Rhone below Geneva, with the limestone which follows the range of the Western Alps from Provence through the Tarentaise and Savoy into the Valais, and continues along the Oberland mountains, across the Lakes of Thun, Brientz, Lucerne, and Wallenstadt, and then beneath the Tyrolese and Styrian Alps, by Innspruck and Salzburg, to the neighbourhood of Vienna. Nor is this the end of the enormous range, for the northern border of the Carpathians about Cracow and Dynow is defined by vast breadths of compact Oolite.

On the southern side of the Alps the same limestones appear in great force, and stretch through Illyria and Carniola to Trent, and the Lakes Guarda, Iseo, Como, Lugano, and Maggiore.

It appears, then, that the sea which deposited the Jurassic rocks covered the areas where now rise on high the Alps, the Carpathians, the Pyrenees, the Auvergne, the Vosges, the Black Forest, and Bohemian mountains, corresponding in general to the basin in which the saliferous system was formed. The original arrangement of the rocks has been in places greatly disturbed, and vast regions have been removed by denudation, yet the general geographical outlines of the system are nearly what they always were. It may not be easy, in the present state of our knowledge, to say what were the depths and the shallows of this great ocean; but even toward this, very considerable approximations may be made by comparing the mineral, zoological, and botanical characters of the deposits in different places.

Divisions of the System.—Notwithstanding their great extent and distribution, it does not appear that the Continental Oolites were anywhere subject to greater variation of composition than the British series.

In the north of France most of the groups may be recognised, as the Lias, Inferior Oolite, Great Oolite, Forest Marble, Oxford Clay, Coralline Oolite, Kimmeridge Clay, and the Portland Oolite and Wealden, and the organic remains are either very similar or identical.

Solenhofen Beds.—In the centre of the German Jura, at Solenhofen and Eichstadt, occur beds of white fissile limestone, now universally employed in lithography, which abound in organic remains, equivalent to or related to the Kimmeridge Clay of England.

TABLE LXXVIII.—*Organic Remains of the Jurassic System.*

See Plates Nos. XVII., XVIII., XIX., XX., XXI., XXII., and XXIII. for many characteristic species.

KINGDOM—PLANTÆ.

ALGÆ.

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Chondrophyllites	1	...	1	...	...
Fucoides	3	...	3	...	...
Halymenites	1	...	1	...	...
Sphærococcites	2	1	1	...	...
Nulliporites	1	1	...	...	...
Zoophycos	1	...	1	...	...
6	9	2	7		

FILICINÆ.

Acrostichites	1	...	1	...	...
Asplenioptéris	1	...	1	...	...
Coniopteris	1	...	1	...	...
Ctenis	2	...	2	...	...
Cyclopteris	3	...	3	...	...
Dichopteris	2	...	2	...	...
Glossopteris	1	...	1	...	...
Hymenophyllites	3	...	3	...	...
Lonchopteris	1	...	1	...	...
Marzaria	1	...	1	...	...
Neuropteris	2	...	2	...	...
Otopteris	1	...	1	...	...
Pachypteris	2	...	2	...	...
Pecopteris	23	...	23	...	...
Phlebopteris	8	...	7	...	1
Polypodites	3	...	3	...	...
Sagenopteris	1	...	1	...	...
Schizopteris	1	...	1	...	...
Sphenopteris	17	...	17	...	...
Tæniopteris	6	...	6	...	...
Tympanopora	2	...	2	...	...
21	82		81		1

EQUISETACEÆ.

Equisetites	3	1	2	...	...
1	3	1	2		

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
LYCOPODIACEÆ.					
Lycopodites	1	...	1	...	...
CONIFERÆ.					
Araucarites	5	1	3	1	...
Brachyphyllum	3	1	2	...	...
Cryptomerites	2	...	2	...	...
Cupressites	1	1	...	...	...
Peuce	3	2	1	...	...
Pinites	3	1	1	...	1
Taxites	2	...	2	...	...
Thuytes	5	...	5	...	...
Walchia	1	...	1	...	...
9	25	6	17	1	1
AROIDEÆ.					
Aroides	1	...	1	...	...
PANDANACEÆ.					
Kaidacarpum	1	...	1	...	..
Podocarya	1	...	1	...	...
2	2		2		
CYCADEÆ.					
Beania	1	...	1	...	...
Bennettites	1	...	...	1	...
Bucklandia	2	...	1	1	...
Cycadeostrobus	2	...	1	1	...
Cycadites	1	...	1	...	...
Cycadeoidea	1	1	...	...	...
Carpolithes	5	...	4	2	...
Otozamites	10	...	10	...	...
Palæozamia	9	2	7	...	...
Podocarya	1	...	1	...	...
Pterophyllum	7	...	7	...	...
Stricklandia	1	...	1	...	...
Williamsonia	3	...	3	..	...
Yatesia	3	1	...	2	...
Zamites	2	...	2	...	...
15	49	4	39	7	
INSERTÆ SEDIS.					
Bensonia	1	...	1	...	...
Carpolithes	5	...	4	2	...
Baiera	3	...	3	...	...
Coniferous wood, &c.	1	...	...	1	...
Lilia	1	...	1	...	...
Naiadites	4	2	2	...	...
Solenites	2	...	2	...	...
Sphærida	2	...	2	...	...
8	19	2	15	3	

CLASS—PROTOZOA.

SPONGIA.

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Diaplectia	2	...	2	...	...
Eusiphonella	1	...	1	...	...
Grantia?	1	1	...	...	...
Manon.	1	...	1	...	...
Peronella	4	...	4	1	...
Lymnorœa	1	...	1	...	...
Inobolia	1	...	1	...	...
Spongia?	5	...	4	1	...
Scyphia	3	...	2	1	...
Spongilla	1	...	...	...	1
Stellispongia	3	...	1	2	...
Talpina	1	...	1	...	...
12	24	1	18	5	1

RHIZOPODA.

FORAMINIFERA.

Bolivina	1	...	...	1	1
Bulimina	1	...	...	1	...
Cornuspira	1	1	...	...	...
Cristellaria	13	12	...	...	1
Dentalina	19	18	...	1	3
Flabellina	1	1	...	...	1
Frondicularia	8	8	...	...	1
Glandulina	4	3	...	...	1
Involutina	1	1	..	...	...
Lingulina.	3	3	...	...	...
Lagena.	7	4	...	...	3
Lituola.	5	4	...	...	2
Marginulina.	13	11	...	...	4
Miliola.	1	1	...	...	...
Nodosaria	9	9	...	...	2
Orbiculina	1	1	...	...	...
Planularia	8	7	...	...	3
Orthocerina.	2	2	...	...	1
Polymorphina	11	9	...	1	4
Planulina	1	...	...	...	1
Pulvinulina.	1	1	...	1	...
Trochamina	4	3	...	...	1
Vaginulina	6	4	...	...	3
Webbina	1	1	...	...	1
Textularia	2	2	...	...	2
Robulina	1	...	...	...	1
Quinqueloculina	1	...	...	...	1
27	126	106		5	37

CŒLENTERATA.

ACTINOZOA.

Anabacia	3	...	3	...	...
Astrocœnia	14	14	...	...	...
Axosmilia	1	...	1	...	...

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Bathycœnia	2	...	2	...	...
Calamophyllia	1	...	1	1	...
Cladophyllia	2	...	1	1	...
Clausastræa	2	...	2	...	...
Comoseris	2	...	1	1	...
Confusastræa	3	...	3	...	...
Convexastræa	1	...	1	...	...
Crateoseris	1	...	...	1	...
Cryptocœnia	3	...	2	1	...
Cyathophyllia	2	...	2	...	...
Cyathocœnia	4	4	...	...	...
Cyathophyllum	1	...	1	...	...
Cyathophora	6	...	6	...	...
Cyclolites	3	1	2	...	...
Cœnotheca	1	...	1	...	...
Choriastræa	3	...	3	...	...
Discocyathus	1	...	1	...	...
Dimorpharæa	4	...	4	1	...
Dimorphoseris	1	...	1	...	...
Donacosmilia	1	...	1	...	...
Enallohelia	1	...	1	...	...
Epismilia	1	...	1	...	...
Elyastræa	2	2	...	...	...
Eunomia	1	.	1	...	...
Favia	1	...	1	...	...
Gonioseris	2	...	2	...	...
Goniocora	2	...	1	1	...
Isastræa	24	10	18	4	1
Latimeandra	8	1	5	2	...
Lepidophyllia	2	2	...	...	...
Microsolena	4	1	4	...	...
Millepora	1	...	1	...	...
Montlivaltia	45	25	18	1	...
Opelismilia	1	1	...	...	...
Oroseris	7	...	7	...	...
Podoseris	1	...	1	...	...
Primastræa	1	...	1	...	...
Protoseris	1	...	...	1	...
Phylloseris	2	...	2	...	...
Rhabdophyllia	2	1	...	1	...
Septastræa	4	4	...	...	...
Stylina	5	...	3	2	...
Symphyllia	1	...	1	...	...
Thamnastræa	27	1	23	3	...
Thecocyathus	1	1	...	...	...
Thecosmilia	21	14	6	1	...
Trochocyathus	3	1	1	1	...
Thecoseris	1	...	1	...	...
Tricycloseris	2	1	1	...	...
52	236	84	139	23	1

Class—ECHINODERMATA.

Echinoidea.

Acrosalenia	12	2	8	1	1
Actinometra	2	...	2	...	...

Genera.	No of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Cidaris	16	3	6	4	3
Clypeus	8	...	8	1	...
Collyrites	3	...	2	1	...
Diplocidaris	2	1	1	...	...
Echinobrissus	10	...	6	5	1
Galeropygus	1	...	1	...	...
Glypticus	1	...	...	1	.
Hemicidaris	13	...	10	1	2
Hemipedina	16	5	6	3	3
Heterocidaris	1	...	1	...	...
Holectypus	3	...	2	1	...
Hyboclypus	4	...	3	1	...
Magnotia	1	...	1	...	...
Pedina	2	...	2	...	...
Pygaster	5	...	2	3	...
Polycyphus	2	...	2	...	...
Pygurus	6	...	1	5	...
Pseudodiadema	17	4	6	3	4
Rhabdocidaris	3	1	2	...	...
Stomechinus	6	...	3	3	...
22	134	16	75	33	14
ASTEROIDEA.					
Astropecten	11	1	9	3	...
Goniaster	3	...	3	...	...
Luidia	1	1	...	...	...
Solaster	1	...	1	...	...
Stellaster	1	...	1	...	...
Tropidaster	1	1	...	...	...
Uraster	3	2	1	...	...
Plumaster	1	1	...	...	...
8	22	6	15	3	
OPHIUROIDEA.					
Acroura	1	1	...	...	...
Amphiura	1	...	1	...	...
Aspidura	1	1	...	...	...
Ophiolepis	3	2	1	...	...
Ophiurella	3	1	1	1	...
Ophioderma	5	5	...	...	...
6	14	10	3	1	
CRINOIDEA.					
Antedon	1	...	1	...	...
Apiocrinus	4	1	3	...	...
Bourgueticrinus	1	...	1	...	...
Extracrinus	2	2	...	...	...
Millericrinus	3	...	2	1	...
Pentacrinus	23	17	5	1	1
Plicatocrinus	1	1	...	...	...
7	35	21	12	2	1

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
HOLOTHURIDÆ.					
Chirodota	2	...	2	...	...
—— remains of	1	1	...	...	...
2	3	1	2		
ANNELIDA.					
Ditrypa	6	6	...	...	...
Galeolaria	1	1	...	...	...
Serpula	26	8	16	8	8
Vermicularia	4	...	1	2	1
Vermilia	3	1	1	1	1
Vermetus	1	...	...	1	...
6	41	16	18	12	10
ARTICULATA.					
CLASS—CRUSTACEA.					
Æger	1	1	...	...	...
Astracus	1	1	...	...	...
Bairdia	4	...	4	...	...
Cythere	7	7	...	...	...
Cytherella	2	2	...	...	...
Cythereis	2	...	...	...	2
Callianassa	1	...	...	...	1
Estheria	2	...	1	1	...
Eryon	8	7	1	...	...
Eryma	5	4	...	...	1
Hefriga	1	1	...	...	...
Glyphæa	11	5	2	6	2
Mecocheirus	2	...	...	1	1
Pagurus	1	...	1	...	...
Palinurina	2	2	...	...	...
Palæinachus	1	...	1	...	...
Pollicipes	8	3	1	2	2
Penæus	2	2	...	...	...
Prosopon	1	...	1	...	...
Pseudoglyphæa	3	3	...	...	...
Polycope	1	1	...	...	...
Scalpellum	1	...	...	...	1
Scapheus	1	1	...	...	...
23	68	40	12	10	10
CLASS—INSECTA.					
COLEOPTERA.					
Berosus	1	1	...	...	...
Coccinella	1	...	1	...	...
Curculionides	1	...	1	...	...
Elaterium	1	1	...	...	...
Gyrinus	1	1	...	...	...
Laccophilus	1	1	...	...	...
Melolontha	1	1	...	...	...
Prionus	1	...	1	...	...
Blapsium	1	...	1	...	...
9	9	5	4		

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
NEUROPTERA.					
Æshnidium	2	2	...	...	...
Agrionidium	2	1	...	...	...
Chauliodes	1	1	...	...	...
Ephemera	1	1	...	...	...
Hemerobioides	2	1	1	...	...
Libellulium	2	2	...	...	...
Orthophlebia	1	1	...	...	...
7	11	9	1		
DIPTERA.					
Asilum	1	1	...	...	...
HOMOPTERA.					
Cicadellium	1	1	...	...	...
Cimilidium	2	1	...	...	...
Ricania	1	1	...	...	...
3	4	3			
ORTHOPTERA.					
Blattidium	1	1	...	...	...
Gryllidium	1	1	...	...	...
2	2	2			
MOLLUSCOIDA.					
Class—**POLYZOA.**					
Aspendesia	2	...	2	...	...
Berenicea	5	2	3	...	...
Ceriopora	2	...	2	...	...
Chrysaora	1	...	1	...	...
Diastopora	15	1	14	1	...
Entalophora	1	...	1	...	...
Fasciculipora	1	...	1	...	...
Heteropora	2	...	2	1	...
Hippothoa	1	...	1	...	...
Idmonea	1	...	1	...	...
Lichenopora	1	...	1	...	...
Neuropora	4	1	3	...	...
Proboscina	1	...	1	...	...
Semitubigera	1	...	1	...	...
Spiropora	6	1	5	...	...
Stomatopora	4	1	3	...	...
Terebellaria	1	1	1	1	...
Theonoa	2	...	2	...	...
Tubipora	1	...	1	...	...
19	52	7	46	3	
Class—**BRACHIOPODA.**					
Argiope	1	...	1	...	...
Crania	8	5	3	...	...
Discina	18	9	5	3	3
Kingæna	1	1	...	...	...
Leptæna	6	6	...	...	...

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Lingula	11	7	1	3	1
Megerlia	2	2	...	...	...
Rhynchonella	76	32	30	6	8
Spiriferina	18	16	2	...	...
Suessia	1	1	...	...	...
Terebratella	5	1	4	...	...
Terebratula	72	20	43	7	2
Terebratulina	4	2	2	...	...
Thecidium	15	9	8	3	...
Waldheimia	44	16	17	10	1
Zelania	6	3	5	1	...
16	288	130	121	33	15

MOLLUSCA.

PELECYPODA.

Monomyaria—

Anomia	9	5	2	2	1
Avicula	42	17	11	12	5
Carpenteria	1	1	...	...	...
Crenatula	2	2	...	...	...
Exogyra	5	...	1	3	4
Gervillia	33	11	22	2	3
Gryphæa	16	7	3	6	1
Harpax	5	2	3	...	...
Hinnites	14	7	6	2	1
Inoceramus	11	6	4	...	1
Lima	73	28	32	12	5
Limæa	4	4	1	...	...
Monotis	6	6	...	...	...
Ostrea	58	18	21	15	8
Pecten	84	32	39	17	11
Perna	15	4	6	3	3
Placunopsis	9	1	6	3	...
Pinna	14	7	6	2	1
Plicatula	17	11	6	1	...
Pteroperna	7	1	6	2	...
Posidonomya	1	1	...	..	...
Spondylus	1	1	...	...	...
Terquemia	1	1	...	...	...
Trichites	3	...	2	1	...

Dimyaria—

Anatina	11	3	4	3	1
Anisocardia	1	...	...	...	1
Arca	45	10	20	10	7
Arcomya	4	4	...	...	...
Astarte	75	17	42	14	9
Cardinia	29	27	1	1	...
Cardita	6	5	...	1	...
Cardium	35	7	16	8	5
Cercomya	1	...	1	...	...
Ceromya	16	3	12	2	1
Corbicella	8	...	7	1	1
Corbis	8	...	6	1	1
Corbula	15	...	9	4	2
Cucullæa	35	9	21	8	2

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Cypricardia	25	13	8	2	2
Cyprina	18	1	10	3	4
Cyrena	6	...	...	6	...
Cytherea	3	...	3	...	...
Dreissena	1	...	1	...	...
Goniomya	15	5	5	1	4
Gouldia	2	...	2	...	...
Gresslya	18	14	4	1	...
Gastrochæna	2	2	...	...	...
Hippopodium	4	4	...	...	...
Homomya	6	2	3	1	1
Isocardia	7	1	3	5	...
Isocarca	2	...	2	...	...
Leda	32	23	5	1	2
Limopsis	1	...	1	...	...
Lithodomus	8	1	5	2	2
Lucina	24	2	10	9	4
Macrodon	6	4	2	...	...
Mactra	1	...	...	...	1
Modiola	44	15	20	8	3
Modiolarca	1	...	1	...	...
Mactromya	1	...	1	1	1
Myacites	33	5	20	8	3
Myoconcha	14	6	5	1	2
Myophoria	1	1	...	...	...
Myopsis	5	...	4	1	...
Mytilus	24	8	10	4	3
Neæra	1	...	1	...	...
Nucula	19	8	6	3	2
Opis	20	4	13	4	1
Pachyrisma	1	...	1	...	..
Panopæa	6	4	2	...	...
Pectunculus	1	...	1	...	...
Pholadomya	48	13	20	13	4
Pholadidea	1	...	...	...	1
Protocardium	4	3	...	...	...
Pholas	5	...	3	1	1
Pleuromya	23	20	3	...	2
Potamomya	3	...	...	3	...
Ptychomya	1	...	1	...	...
Pullastra	2	1	1	...	...
Quenstedtia	4	1	3	1	...
Sanguinolaria	4	2	2	...	...
Saxicava	3	3	...	...	...
Sphæra	1	...	1	...	...
Solemya	1	...	...	1	...
Sowerbya	6	1	2	2	2
Solen	1	1	...	...	...
Tancredia	26	12	14	1	...
Tellina	3	2	...	1	...
Terquemia	1	1	...	...	...
Thracia	8	4	4	4	1
Trigonia	88	6	63	18	14
Unicardium	11	3	5	2	2
Unio	3	...	3	1	..
93	1319	454	590	245	136

Class—GASTEROPODA.

Genera.	No. of Species.	JURASSIC.			
		Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Acmæa	1	1	...	...	...
Actæon	9	3	5	1	...
Actæonina	26	8	18	...	...
Alaria	38	6	27	6	2
Amberleya	11	5	6	1	...
Ampullaria	3	3	...	...	...
Brachytrema	6	...	6	...	...
Buccinum	2	...	...	2	2
Bulla	3	...	3	...	...
Ceritella	16	...	16	...	...
Cerithium	98	54	28	8	11
Chemnitzia	50	23	19	3	1
Chiton	3	3	...	...	...
Cirrus	4	...	3	1	...
Cryptaulax	1	1	...	...	...
Crossostoma	3	...	3	...	...
Cylindrites	19	1	16	2	...
Delphinula	9	1	7	...	1
Dentalium	14	12	1	2	1
Deslongchampsia	1	...	1	...	...
Discohelix	9	9	...	...	...
Ditremaria	1	...	1	...	...
Emarginula	5	...	5	...	...
Eucyclus	2	2	...	...	...
Euspira	10	...	10	...	...
Eulima	15	10	5	...	...
Exelissa	1	1	...	...	...
Fissurella	2	...	2	...	...
Fusus	7	2	4	1	...
Fibula	3	...	3	...	...
Hydrobia	2	...	1	1	...
Kilvertia	4	...	4	...	...
Leptoxis	1	...	...	1	...
Littorina	19	5	8	5	1
Melania	11	9	1	1	...
Monodonta	20	1	19	...	...
Natica	49	4	22	11	12
Nerinæa	32	4	21	10	...
Nerita	16	1	13	2	1
Neritina	5	3	1	1	...
Neritoma	1	...	...	...	1
Neritopsis	14	5	6	5	1
Onustus	5	3	2	...	...
Orthostoma	6	6	...	...	...
Paludina	1	...	...	1	...
Patella	25	9	14	3	1
Phasianella	20	6	13	1	...
Pitonellus	4	4	...	...	...
Pileolus	2	...	2	...	...
Planorbis	1	1	...	...	...
Pleuratella	1	1	...	...	...
Pleurotomaria	101	38	53	10	2
Proserpina	1	1	...	...	...
Pseudomelania	1	...	1	...	...
Pterocheilus	1	1	...	...	...
Pterocera	4	1	3	...	...

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Purpuroidea	10	2	8	1	...
Pyrula	1	1	...	...	...
Rimula	7	3	4	...	...
Rissoa	3	1	1	...	1
Rissoina	12	...	11	...	1
Rostellaria = Alaria	...	...	...	...	...
Rotella	1	1	..	...	...
Scalaria	2	1	1	...	...
Solarium	14	7	7	...	...
Spinigera	1	...	1	...	...
Straparollus	10	6	3	1	...
Tectaria	3	3	...	...	...
Tornatella	7	7	...	...	2
Trochotoma	14	4	10	1	...
Trochus	80	41	35	4	3
Turbo	85	55	24	7	2
Turritella	16	11	2	2	1
Valvata	3	2	...	1	...
74	988	393	480	96	47
Class—CEPHALOPODA.					
Acanthoteuthis	1	...	...	1	1
Ammonites	417	246	66	77	39
Ancyloceras	2	...	1	1	...
Belemnites	112	69	20	14	10
Beloteuthis	2	2	...	...	...
Coccoteuthis	1	...	..	...	1
Geoteuthis	1	1	...	1	...
Nautilus	21	9	11	3	1
Rhyncholites	1	1	...	...	..
Trigonellites	1	1	...	1	...
Xiphoteuthis	1	1	...	...	...
11	560	330	98	98	52
CLASS—PISCES.					
Cestraciontidæ. PLACOIDEI.					
Hybodus	23	9	10	1	3
Sphænonchus	3	1	1	...	1
Acrodus	7	5	2	...	...
Asteracanthus	6	...	5	...	1
Ceratodus	1	...	1	...	...
Leptacanthus	3	1	2	...	...
Nemacanthus	2	...	2	...	
Pristacanthus	1	...	1	...	...
Strophodus	7	...	5	1	1
9	53	16	29	2	6
Raiidæ.					
Arthropterus	1	1	...	...	...
Cyclarthrus	1	1	...	...	...
Myriacanthus	3	3	...	...	...
Squaloraia	1	1	...	...	...
4	6	6			

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Edaphodontidæ					
Ganodus	10	...	10	...	...
Ischyodus	4	2	...	...	2
2	14	2	10		2
Spinacidæ.					
Palæospinax	1	1	...	...	...
Prognathodus	2	2	...	...	...
2	3	3			
	GANOIDEI.				
Sauroidei.					
Aspidorhynchus	2	1	...	1	...
Belonostomus	4	2	2	...	...
Endactis	1	1	...	...	...
Caturus	2	1	1	...	1
Centrolepis	1	1	..	...	...
Chondrosteus	3	3	...	...	...
Conodus	1	1	...	...	...
Cosmolepis	1	1	...	...	...
Ditaxiodus	1	...	...	...	1
Eugnathus	12	12	...	...	...
Isocolum	1	1	...	...	...
Leptolepis	9	6	...	3	...
Heterolepidotus	3	3	...	...	...
Macrosemius	1	...	1	...	...
Osteorachis	1	1	...	...	...
Oxygnathus	1	1	...	...	...
Oxygonus	1	1	...	...	...
Pachycormus	11	11	...	...	...
Platysiagmus	1	1	...	...	...
Ptycholepis	3	3	...	...	...
Sauropsis	1	...	1	...	...
Thlattodus	1	...	...	...	1
Thrissonotus	1	1	...	...	...
Pycnodontidæ.					
Gyrodus	7	...	2	2	4
Gyronchus	1	...	...	...	1
Mesodon	1	1	...	...	...
Pycnodus	15	1	13	...	1
Scaphodus	1	...	1	...	...
Sphærodus	1	...	...	...	1
Tetragonolepis	1	1	...	...	...
Lepidoidei.					
Æchmodus	13	13	...	...	...
Amblyurus	1	1	1	...	...
Dapedius	8	8	...	...	...
Eulepidotus	1	1	...	...	...
Histionotus	1	...	...	1	...
Lepidotus	8	5	2	1	...
Nothosomus	1	1	...	...	...
Pholidophorus	12	10	2	...	...

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Pleuropholis	1	...	...	...	1
Semionotus	2	1	...	...	1
Cœlacanthidæ.					
Ctenolepis	1	...	1	...	..
Holophagus	1	1	...	...	...
Gyrosteus	1	1	...	...	...
Isodius	1	...	1	...	...
Macropoma	1	...	...	...	1
45	143	97	28	8	14

PROVINCE—SAUROPSIDA.

Class—REPTILIA.

Deinosauria.					
Cardiodon	1	...	1	...	..
Gigantosaurus	1	...	...	...	1
Iguanodon	1	...	...	1	1
Megalosaurus	3	2	2	1	1
Omosaurus	1	...	...	...	1
Priodontognathus	1	...	...	1	..
Scelidosaurus	1	1	...	...	...
6	9	3	3	3	4
Crocodilia.					
Bothriospondylus	2	...	1	...	1
Cetiosaurus	5	...	4	...	2
Cryptosaurus	1	...	...	...	1
Dakosaurus	3	...	...	...	3
Goniopholis	1	...	...	...	1
Streptospondylus	2	...	2	1	...
Stenosaurus	6	1	...	...	5
Teleosaurus	7	2	3	...	2
8	27	3	10	1	15

ERPETOSPONDYLIA.

Lacertilia.					
Lacerta	1	...	1	...	...

PEROSPONDYLIA.

ENALIOSAURIA.

Ichthyosauria.					
Ichthyosaurus	24	15	2	2	7
Ophthalmosaurus	1	...	...	1	...
2	25	15	2	3	7

Order { SAUROPTERYGIA, Owen. / PLESIOSAURIA, Huxley.

Genera.	No. of Species.	JURASSIC. Lowr. Mid. and Up. Lias.	Lower.	Middle.	Upper.
Plesiosaurus	37	21	?	4	12
Pliosaurus	7	...	...	1	6
Mursenosaurus	1	...	...	1	...
Dinotosaurus	1	...	...	1	1
Rhomaleosaurus	1	1	...	...	...
5	47	22		7	19
Chelonidæ.					
Chelys	1	...	...	...	1
Enalochelys	1	...	...	...	1
Pelobatochelys	1	...	...	...	1
Testudo	2	...	2	...	...
Trionyx	1	...	...	1	...
5	6		2	1	3
PTEROSAURIA. (*Ornithosauria*, Seeley.)					
Pterodactylia.					
Dimorphodon	1	1	...	...	...
Pterodactylus	7	1	3	...	3
Rhamphocephalus	1	..	1	...	...
Ramphorhynchus	3	...	3	...	...
4	12	2	7		3
MAMMALIA.					
Didelphidæ.					
Amphilestes	1	...	1	...	...
Amphitherium	3	...	3	...	...
Phascolotherium	1	...	1	...	..
Stereognathus	1	...	1	...	..
4	6		6		

TABLE LXXIX.—*Exhibiting the Fauna and Flora of the Jurassic Rocks in Britain, with Range of Species, numerically shown through the whole System, or from the Lower Lias to the Portland Rocks.*

Classes, &c.		Number of Genera.	Number of Species.	Lower Jurassic.								Mid. Jurassic.			Upper Jurassic.	
				Lias.			Inferior Oolite.	Fuller's Earth.	Great Oolite.	Forest Marble.	Cornbrash.	Kellaways Rock.	Oxford Clay.	Corallian Beds.	Kimmeridge Clay.	Portlandian.
				Lower Lias.	Middle Lias.	Upper Lias.										
	Plantæ	64	191	1/8	...	1/2	1/16	...	8/8	...	...	...	1/2	4/4	1/1	...
	(Protozoa) Spongia	12	25	3/3	...	...	2/2	...	1/1	...	...	...	...	...	...	...
	Rhizopoda	27	126	10/10	4/4	11/11	...	...	...	...	...	...	4/4	...	1/1	...
	Cœlenterata	52	236	17/17	8/8	8/8	3/3	1/1	11/11	1/1	11/11	...	...	...	...	1/1
	Echinodermata	45	208	12/12	1/1	7/7	2/2	1/1	11/11	1/1	11/11	1/1	1/1	4/4	1/1	1/1
	Annelida	6	41	1/1	1/1	1/1	1/1	...	1/1	...	1/1	1/1	1/1	1/1	1/1	1/1
	Crustacea	23	68	11/11	1/1	1/1	1/1	...	1/1	...	1/1	1/1	1/1	1/1	1/1	1/1
	Insecta	22	27	1/1	...	...	...	...	...	...	...	...	...	...	..	...
	Polyzoa	19	52	2/2	1/1	1/1	1/1	...	1/1	...	1/1	...	...	...	...	...
	Brachiopoda	16	288	10/10	7/7	11/11	7/7	1/1	11/11	1/1	11/11	1/1	1/1	1/1	1/1	1/1
Pelecypoda. 93 genera and 1319 species.	Monomyaria	24	431	11/11	8/8	11/11	10/10	1/1	8/8	1/1	8/8	1/1	1/1	1/1	1/1	1/1
	Dimyaria	69	888	35/35	10/10	11/11	11/11	1/1	10/10	1/1	11/11	1/1	1/1	1/1	1/1	1/1
	Gasteropoda	74	988	35/35	11/11	11/11	11/11	1/1	11/11	1/1	11/11	1/1	1/1	1/1	1/1	1/1
Cephalopoda.	Ammonites	1	417	17/17	8/8	7/7	7/7	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1	1/1
	Ancyloceras	1	2	...	...	...	1/1	...	...	...	...	1/1	1/1	...	...	...
	Nautili	1	21	1/1	1/1	1/1	1/1	...	1/1	...	1/1	1/1	...	...	...	...
	Belemnites	1	112	5/5	5/5	4/4	1/1	1/1	1/1	...	...	1/1	1/1	1/1	...	...
	Teuthidæ	7	8	1/1	1/1	1/1	...	...	...	...	...	...	1/1	...	...	...
	Pisces	62	219	10/10	4/4	1/1	1/1	...	11/11	1/1	1/1	1/1	...	...	1/1	1/1
	Reptilia	31	127	1/1	1/1	1/1	...	...	1/1	...	1/1	...	1/1	...	1/1	1/1
	Mammalia	4	6	...	...	...	...	...	1/1	...	...	..	...	...	...	...
		561	4481	240/1105	127/885	111/718	111/1003	11/110	111/887	14/128	22/172	12/102	18/104	115/113	108/183	66/118

PLATE XXIII *A*.

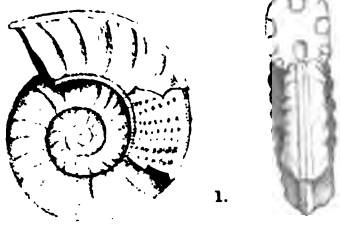
CHARACTERISTIC JURASSIC AMMONITES.

1. *Ammonites* (*Arietites*) *obtusus* (Sow.) Lower Lias.
   Group *Arietites*. Fam. *Ægoceratidæ*.
2. *Ammonites* (*Harpoceras*) *serpentinus* (Rein.) Upper Lias.
   Group *Harpoceras*. Fam. *Harpoceratites*.
3. *Ammonites* (*Amaltheus*) *cordatus* (Sow.) Oxford Clay, and Coral Rag, &c.
   Group *Amaltheus*. Lias to Coral Rag.
4. *Ammonites* (*Cosmoceras*) *Duncani* (Sow.) Oxford Clay and Kellaways Rock.
   Group *Ornati*. Fam. *Stephanoceratites*.
5. *Ammonites* (*Ægoceras*) *armatus* (Sow.) Lower Lias.
   Group *Ægoceras*. Fam. *Stephanoceratites*.
6. *Ammonites* (*Ægoceras*) *capricornus* (Schloth.) Middle Lias.
   Group *Ægoceras*. Fam. *Ægoceratites*.
7. *Ammonites* (*Phylloceras*) *heterophyllus* (Sow.) Upper Lias. Chiefly Whitby.
   Group *Heterophylli*. Fam. *Phylloceras*.
8. *Ammonites* (*Stephanoceras*) *annulatus* (Sow.) Upper Lias—*passim*.
   Group *Planulati*. Fam. *Stephanoceratites*.

PLATE XXIII.

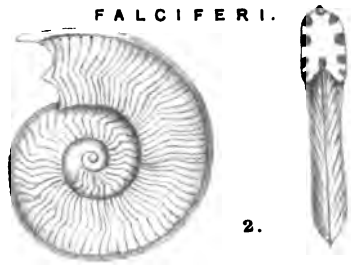
CHARACTERISTIC JURASSIC AMMONITES.

ARIETITES.



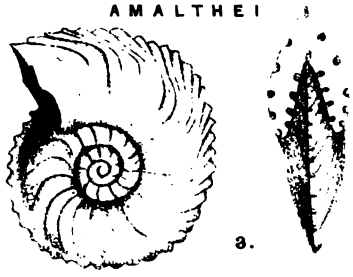
1.

FALCIFERI.



2.

AMALTHEI



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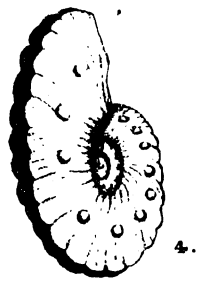
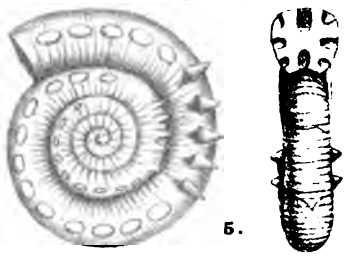
ORNATI.



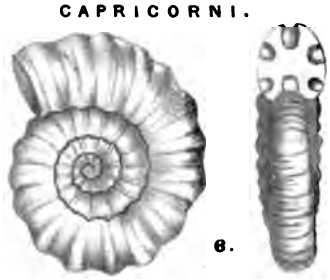
4.

ARMATI.



5.

CAPRICORNI.



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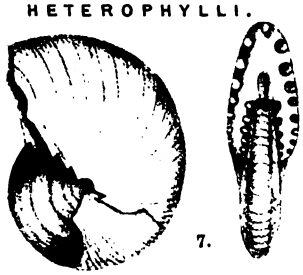
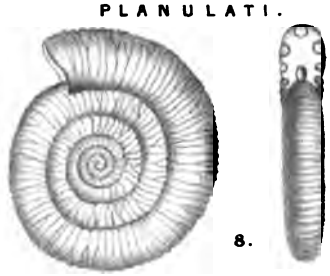
HETEROPHYLLI.



7.

PLANULATI.



8.

PLATE XXIII *B.*

JURASSIC AMMONITES AND STRUCTURAL PARTS.

1. *Ammonites* (*Stephanoceras*) *Bechei* (Sow.) Middle Lias. Cheltenham and Lyme Regis.
   Group *Coronarii.* Fam. *Stephanoceratites.*
2. *Ammonites* (*Stephanoceras*) *macrocephalus* (Schloth.) Cornbrash and Oxford Clay.
   Group *Macrocephali.* Fam. *Stephanoceratites.*

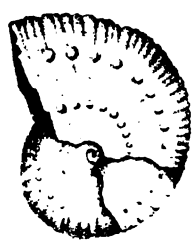
3-4. *Ammo.* (*Stephanoceras*) *Braikenridgii* (Sow.) Inferior Oolite.
   Group *Coronarii.* Fam. *Stephanoceratites.*
   These two figures show the side and front view of the so-called labial prolongations, or complete mouth or aperture.

5. Section showing the aperture or end view of *Ammo. Heterophyllus*, and position of the lobes and saddles (L. = Lobes, S. = Saddles, D. = Dorsal, and V. = Ventral lobes).
6. Forms and disposition of the lobes and saddles.
7. Disposition of the lobes—front view of base of body-chamber—D. = Dorsal lobe, V. = Ventral, L. = Lateral lobe, L^1. = Inferior lateral lobe. The intermediate spaces are occupied by the saddles.
8. *Ammonites* (*Harpoceras serpentinus*). Showing extension of the siphona or ventral area, and sigmoidal folds or successive growth of the shell.

PLATE XXIII[b]

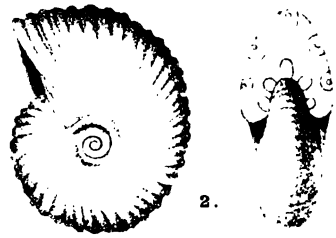
JURASSIC AMMONITES AND STRUCTURAL PARTS.

CORONARII.



1.

MACROCEPHALI.



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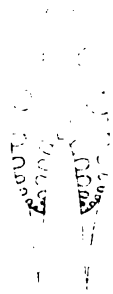
3.



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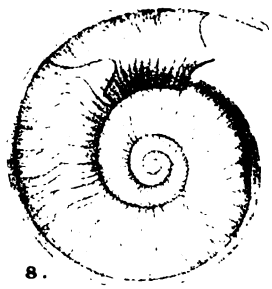
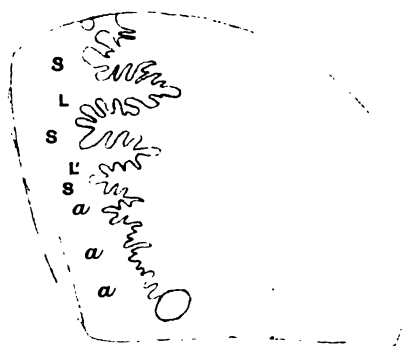
4.



8.



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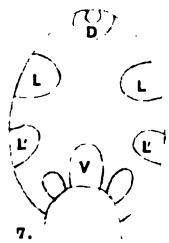

7.

CHAPTER XLIII.

PURBECK FORMATION.[1]

History.—This fresh-water group of strata is so named from its occurrence and development in the Isle or Peninsula of Purbeck (in Dorsetshire). Hitherto it has been classed with the Wealden formation; and even now we may doubt its true place as the summit or highest zone of the Jurassic series of England. Many details and peculiarities tend to show that it should be separated from the Jurassic system proper, for the beds were accumulated at a period when the physical geography and entire fauna of the area were undergoing complete change. The preceding Portland beds were slowly upraised, and must have undergone denudation before the lowest of the Purbeck strata were deposited.[2] A complete break, both stratigraphically and palæontologically, took place at this time. The Portlandian sea-floor became partly land, or was converted into shallow estuaries. The fauna of the Jurassic seas, purely marine, with few exceptions (*Pecten*, *Modiola*, *Ostræa*, *Avicula*, *Trigonia*, &c.), had passed away from the area of oscillation, and its place was supplied by terrestrial, fresh-water, and brackish-water species. The Purbeck strata consist of fresh-water limestones, clays, shales, and sandstones, and are divided into three groups or sections—an *upper*, with Purbeck marble; *middle*, with cinder beds (marine), 130 feet; and *lower series*, with dirt-beds, 140 feet. The Lower Purbeck at Lulworth is divided into nine sections or beds, the whole comprising 176 feet, the lowest being the well-known "*Dirt-bed*," which contains stumps of Cycadeæ (*Mantellia nidiformis*). The Middle division in five sections contains marine and fresh-water fossils, whilst the four Upper beds return again to fresh-water conditions. Commencing at the base or the dirt-bed, which immediately rests upon the eroded Portland, we have in succession the following subdivisions, seen on the east side of Lulworth Cove, in ascending order:—

[1] Mr. Blake would class the Purbeck with the Portland limestone under the term *Portlandian*, as the uppermost group of the Jurassic system.

[2] See J. F. Blake "On the Portlandian Rocks of England." Q. J. Geol. Soc., vol. xxxvi.; Swindon, pp. 203–13; and Portland, p. 190.

TABLE LXXX.—*Sequence of Purbeck Strata at Lulworth.*[1]

	No.		Ft.	in.
Lower Purbeck. Marine and Fresh-water.	1.	*The Dirt-bed*, with *Mantellia nidiformis*	1	0
	2.	*The Hard Cap.*—Tufaceous limestone and layers of flint	4	6
	3.	*The Soft Cap.*—Limestone bands undulating over cycas-stools	5	0
	4.	*Broken Bands.*—Shattered slaty limestone, with fragments of flints	10	0
	5.	Sandy partings	1	0
	6.	*Cypris Freestone.*—Soft slaty limestone (*Cypris*) layers of pseudomorphous crystals of rock-salt. *Cypris punctata, C. Purbeckensis, Rissoa, Planorbis.* Sandy limestone with casts of fossils, and shales and limestones, ending upwards, with cream-coloured slaty limestone	21	0
	7.	*Hard-Cockle beds.*—Hard fissile limestone at the top. Yellow sandy limestone, ripple-marked on under-surface, 2 feet; shelly limestone, 6 feet; dark shale, 2 feet	14	0
	8.	*Soft-Cockle beds.*—Hard and soft marls, 7 feet; pale grey limestone and shaly partings, 3 feet 6 inches; dark shales and limestone bands. *Cypris* (2 sp.), fish-remains, pseudomorphs, crystals of rock-salt, 13 feet; grey shales and limestone bands, &c. &c.	39	0
	9.	*Marly Fresh-water.*—Thin limestones, 2 feet; hard band in centre, 2 feet 6 inches; scales of fish, *Lepidotus, Hydrobia, Physa, Limnæa, Planorbis*	12	6
Middle Purbeck. (Marine.)	10.	*Cherty Fresh-water.*—Dark sandy shales, 2 ft. cream-white limestone, with three distinct layers of black chert	5	9
	11.	*Cinder.*—Soft cinder, 1 ft. 6 in. Hard cinder, vast accumulation of *Ostrea distorta* (on this bed in Meups Bay Prof. Forbes discovered *Hemicidaris Purbeckensis*)	4	0
	12.	*Scallop beds.*—Hard shell limestone		
		Intermarine beds—Dark shales, lines of perished shells, 2 ft. in. Bands of hard limestone ("Beef")	1	10
	13.	*Corbula beds.*—Hard limestone, with fish spines (*Asteracanthus*), 1 ft. 9 in. *Ostrea, Pecten, Cyrena.* Dark-grey shales	15	0
	14.	*Chief "Beef" beds.*—Bands of dark soft clay, hard-shell limestone, *Cyrena.* "Beef," with lines of perished shells.	8	3
Upper Purbeck. Fresh-water.	15.	*Broken-shell Limestone.*—Fish teeth and palates, numerous scales (*Pycnodus*) *Paludina, Limnæa*	3	6
	16.	*Unio beds.*—Soft green shale full of Unio. Bands of hard limestone, "Beef" shelly limestone, and dark-grey shales	7	9
	17.	*Upper Cypris Clays and Shales*	13	6
	18.	*Paludina Clays.*—Paludina limestone and *Pycnodus*	2	3
			169	10

Hastings sand and Weald clay above, faulted vertically against the upper beds.

[1] At Meups Bay, the Purbeck series measure about 155 feet; at Ridgway Hill 190 feet. All the beds of the *upper series* are fossiliferous, and also those from the *Corbula beds* downwards.

The total thickness of the Purbeck beds *exposed in Sussex* is about 330 feet; the greater part consists of shales. The limestones occur on two horizons—an upper series locally called "*Greys*," and a lower known as "*Blues*."

Upper Purbeck.	*a.*	Beds above the "Greys"	30 feet.
	b.	"*Greys*" or "Vein Greys," with associated shales	45 „
	c.	Strata, mostly shales with their limestones	130 „
Lower Purbeck.	*d.*	"*Blues*," with associated shales	25 „
	e.	Beds below the "Blues"	100 „
			330 „ [1]

The "Greys" and the beds above them are very fossiliferous; the "Blues" much less so; whilst the lower beds are almost unfossiliferous.

None of the characteristic Purbeck *Cyprideæ* have been discovered in these beds, therefore the palæontological evidence of their Purbeck age is not really conclusive. As another point of difference, we may note that *Paludinæ* are rare in the Sussex Purbecks, whilst they form entire beds in the Dorsetshire series—*the well-known Purbeck marble.*

The *lowest visible* strata of Sussex are seen in some of the woody valleys near Battle, where limestones and shales belonging to the *Purbeck rocks* occur. From old workings, and the upper part passed through in the late sub-Wealden boring, we learn that these *Purbeck beds* have a thickness of about 400 feet. Further, it is proved that these Sussex Purbecks are underlaid by an equivalent of the *Portland beds* about 100 feet thick, succeeded below by the Corallian, Oxfordian, and Kimmeridge Clay beds upwards of 800 feet thick.

Purbeck Fauna.—The entire fauna of the Purbeck beds comprises 138 genera and 219 species. The most remarkable of the classes enumerated are the Insecta, Reptilia, and Mammalia.[2]

Fifty of the 95 species of the Insecta occur in the Lower Purbeck, 10 species only being known in the Middle. All the species of Fish, except *Asteracanthus semi-verrucosus* and *Asphidorhynchus Fischeri*, are Middle Purbeck. The most characteristic species are *Histionotus angularis, Lepidotus minor, Microdon radiatus, Oxygonius tenuis, Ophiopsis dorsalis*, and *Leptolepis Brodiei*.

The Reptilia are represented by 5 families—the Chelonia, Crocodilia, Lacertilia, Cœlospondilia, and the Pterosauria.

The Crocodilia by 5 genera—*Nannosuchus, Macrorhynchus, Theriosuchus, Pterosuchus*, and *Goniopholis*.

The Lacertilia through *Echinodon, Macellodon, Nuthetes* and *Saurillus*.

The Chelonia by *Chelone, Pleurosternon*, and *Tretosternon*.

The Pterosauria by *Doratorhynchus;* and the Cœlospondilia by *Poikilopleuron*.

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[1] Consult Mr. Topley's "Memoir upon the Geology of the Weald" (Mem. Geol. Surv., 1875); also Dixon's "Sussex," second edition.

[2] Two horizons in England, the *Stonesfield slate* and the *Purbeck*, have yielded these small marsupials; the former 4 genera, and the group under consideration 12 genera and 28 species, and all from the Middle beds; most of the species of Reptilia are also Middle Purbeck, *Saurillus obtusus* being the only Lower Purbeck form.

Mammalia.—The whole of the known 12 genera and 20 species belong to the group Marsupialia, and all occur in the marly fresh-water beds of the Middle Purbeck immediately below the cherty fresh-water series. They are *Achyrodon nanus, Amblotherium soricinum, A. mustelula, Bolodon crassidens, Peramus tenuirostris,* and *var minor, Perlastes longirostris, Perlastes* sp., *Peraspalax talpoides, Plagiaulax Becklesii, P. minor, P. Falconeri, P. medius, Spalacotherium tricuspidens, S. minus, Stylodon pusillus, S. robustus, Triacanthodon serrula,* and *Triconodon ferox. T. major, T. mordax,* and *T. occisor.* Below the Mammalian beds, or marly fresh-water series which terminates the downward succession of the Middle Purbecks, few or no Vertebrata occur, the marly and gypsum series mostly yielding the Insecta.

The accompanying table shows the numerical value of the Purbeck fauna. The preponderance both in genera and species of the Insecta and the smallness of the Molluscan fauna are two special features in the history of the Purbeck Rocks. So with the Reptilia and Mammalia. Only 21 genera and 36 species (with the exception of the Insecta) pass to the Wealden, and this is chiefly through the Mollusca.

TABLE LXXXI.—*Numerical Distribution of the Fauna and Flora of the Purbeck Rocks and Relation to the Wealden or Lowest Cretaceous.*[1]

Classes.		Purbeck. Genera.	Species.	Pass to Wealden.
	Plantæ	5	7	⅖
	Echinodermata	1	1	
	Annelida	1	1	
	Crustacea	2	9	⅓
Insecta.	Coleoptera	17	33	
Insecta.	Neuroptera	15	18	
Insecta.	Diptera	13	15	
Insecta.	Homoptera	11	18	
Insecta.	Orthoptera	5	9	
Insecta.	Hymenoptera	2	2	
Pelecypoda.	Dimyaria	9	17	5/17
Pelecypoda.	Monomyaria	4	5	¼
	Gasteropoda	9	11	⅛
	Cephalopoda	1	1	...
Pisces.	Placoidei	2	3	⅔
Pisces.	Ganoidei	13	21	¼
Reptilia.	Crocodilia	7	8	¼
Reptilia.	Lacertilia	4	4	...
Reptilia.	Chelonidæ	3	6	⅔
Reptilia.	Pterosauria	1	1	...
Reptilia.	Cœlospondilia	1	1	...
	Mammalia	12	28	...
In all, 138 genera, 219 species, 11/36 passing to Wealden.				

[1] No species pass up from the Portland to the Purbeck rocks.

TABLE LXXXII.—*Organic Remains of the Purbeck Strata.*

(See Plate XXIV., figs. 7, 8, 9, and 10.[1])

KINGDOM—PLANTÆ.	No. of Species.	Pass to Wealden.
Bennettites	1	1
Chara	1	1
Dammarites	1	...
Mantellia	3	...
Pinites	1	1
	7	3
ECHINODERMATA.		
Hemicidaris	1	...
ANNELIDA.		
Serpula	1	...
CRUSTACEA.		
Archæoniscus	2	...
Cypridea	7	5
	9	5
INSECTA.[2]		
COLEOPTERA.		
Agrillium	4	4
Buprestium	7	7
Carabus	2	2
Cerylon	1	1
Cimicidium	1	1
Columbetes	1	1
Cyphon	1	1
Curculium	1	1
Ctenicerium	2	2
Diaperidium	1	1
Elaterium	4	4
Harpalidium	2	2
Helopidium	2	2
Helophorus	1	1
Limnius	1	1
Rhyncophora	1	1
Telephorium	1	1
	33	33

NEUROPTERA.	No. of Species.	Pass to Wealden.
Æshnidium	2	2
Æshna	1	1
Agrionidium	1	1
Carabidium	1	1
Corydalis	1	1
Libellulium	2	2
Lindenia	1	1
Panorpidium	1	1
Phryganidium	1	1
Phryganea	1	1
Rhaphidium	1	1
Tentridium	1	1
Termitidium	2	2
Termes	1	1
Sialium	1	1
	18	18
DIPTERA.		
Cecidomidium	1	1
Chironomus	2	2
Corethrium	1	1
Culex	1	1
Empidium	1	1
Macrocerium	1	1
Macropezium	1	1
Platyura	1	1
Rhyphus	1	1
Sciophyla	1	1
Sinulium	1	1
Tanypus	1	1
Simulidium	2	1
	15	14
HOMOPTERA.		
Aphis?	2	2
Aphidium	2	...
Asiracum	1	1
Cercopidium	5	5
Cicadellium	2	2
Cicada	1	1
Cixium	1	1
Delphax	1	1

[1] The column headed "Wealden" shows the number of species that are common to or that pass from the Purbeck to the Wealden strata.

[2] Much doubt exists relative to the history of the fossil Insecta. $\frac{6}{11}$ may be common to the two groups.

TABLE LXXXII.—(*Continued*).

	No. of Species.	Pass to Wealden.
Kleidocerys	1	1
Nepidium	1	1
Ricania	1	1
	18	16
ORTHOPTERA.		
Achitidium	1	1
Achæta	1	1
Blattidium	5	5
Blatta?	1	...
Gryllidium	1	1
	9	8
HYMENOPTERA.		
Formicium	1	1
Myrmecium	1	1
	2	2
CLASS—MOLLUSCA.		
PELECYPODA.		
Ostrea	1	1
Pecten	1	...
Perna	2	...
Gryphæa	1	...
	5	1
Anodonta	1	...
Cardium	2	2
Corbula	1	1
Cyrena	6	6
Mytilus	1	1
Pholadomya	2	2
Psammobia	1	...
Trigonia	1	...
Unio	2	...
	17	12
GASTEROPODA.		
Cerithium	2	2
Limnæa[1]	?	...
Melanopsis	2	1
Natica	1	1
Physa	1	...
Paludina	4	4
Planorbis[1]	?	...
Rissoa[1]	?	...
Tornatella	1	1
	11	9
CEPHALOPODA.		
Teudopsis	1	...
CLASS—PISCES.		
PLACOIDEI.		
Asteracanthus	2	1
Hybodus	1	1
	3	2
GANOIDEI.		
Aspidorhynchus	1	...
Ceramus	1	...
Histionotus	1	...
Lepidotus	1	1
Leptolepis	2	...
Megalurus	2	...
Microdon	1	...
Ophiopsis	3	...
Oxygonius	1	...
Pholidophorus	2	...
Pleuropholis	5	...
Pycnodus[1]	...	...
Sphærodus	1	...
	21	1
CLASS—REPTILIA.		
CROCODILIA.		
Brachydectes	2	...
Goniopholis	1	1
Macrorhynchus	1	...
Nannosuchus	1	...
Pterosuchus	1	...
Sphænospondylus	1	...
Theriosuchus	1	...
	8	1
LACERTILIA.		
Echinodon	1	...
Macellodon	1	...
Nuthetes	1	...
Saurillus	1	...
	4	
CHELONIDÆ.		
Chelone	1	1
Pleurosternon	4	...
Tretosternon	1	1
	6	2

[1] Fragments only.

TABLE LXXXII.—(*Continued*).

	No. of Species.	Pass to Wealden.
PTEROSAURIA.		
Doratorhynchus . .	1	...
CŒLOSPONDILIA.		
Poikilopleuron . .	1	?
Class—MAMMALIA.		
Amblotherium . .	2	...
Achyrodon . . .	2	...
Bolodon	1	...
Leptocladius . . .	1	...
Peramus . . .	2	...
Perlastes . . .	2	...
Peraspalax . . .	1	...
Plagiaulax . . .	4	...
Spalacotherium . .	2	...
Stylodon . . .	2	...
Triacanthodon . .	1	...
Triconodon . . .	8	...
	28	

PART VII.

UPPER MESOZOIC STRATA.

CHAPTER XLIV.

GENERAL VIEW OF THE CRETACEOUS SYSTEM.

Mineral Character.—That a peculiar type of mineralogical or lithological character belongs to each system is sufficiently evident through the whole course of our investigation. The gneiss and mica slate of the Cambrian and Silurian systems, the limestones of the Carboniferous series, the coloured marls and Magnesian limestones of the Permian, the Saliferous and Jurassic systems, all strongly impress upon us the distinctive physical features of the several periods at which these different sedimentary rocks were produced or accumulated.

Mineral characters alone, when rightly used, are in many instances sufficient to determine the geological relations of even distant regions; and when conjoined with the evidence of organic remains, they form a secure groundwork for stratigraphical geology.

The Cretaceous system is as definite as any of the others with respect to the distinctness of its prevailing mineral ingredients, and not less characteristically marked by its organic remains. Chalk and Greensand are terms understood by all the geologists of northern Europe; and even on the southern side of the Alps their representatives may be recognised.

Range of the Cretaceous System.—The principal range of the Cretaceous rocks is included within the general boundaries of the European basin, and is not less extensive than the Jurassic system, though, by the spread of Tertiary rocks above it, its course over large tracts of country is wholly covered or hidden.

The Cretaceous system of Ireland is in a depression, on the western side of what is usually understood by the basin of Europe. It consists of chalk 200 or 300 feet thick, more indurated than the ordinary English chalk, but with a similar though less extensive suite of organic remains, and rests on the Upper Greensand or Cenomanian, there called *mulatto*, with the usual characters of that group in England. Lower Lias is found beneath the Chalk at the Giant's Causeway. In Scotland, in addition to the Cretaceous strata of the Western Highlands, only dubious indication of the former extent of the Cretaceous system is afforded by certain flints which rest upon Primary rocks near Peterhead.

Within the natural modern boundaries of the principal basin of European Secondary strata, the Cretaceous system is very largely

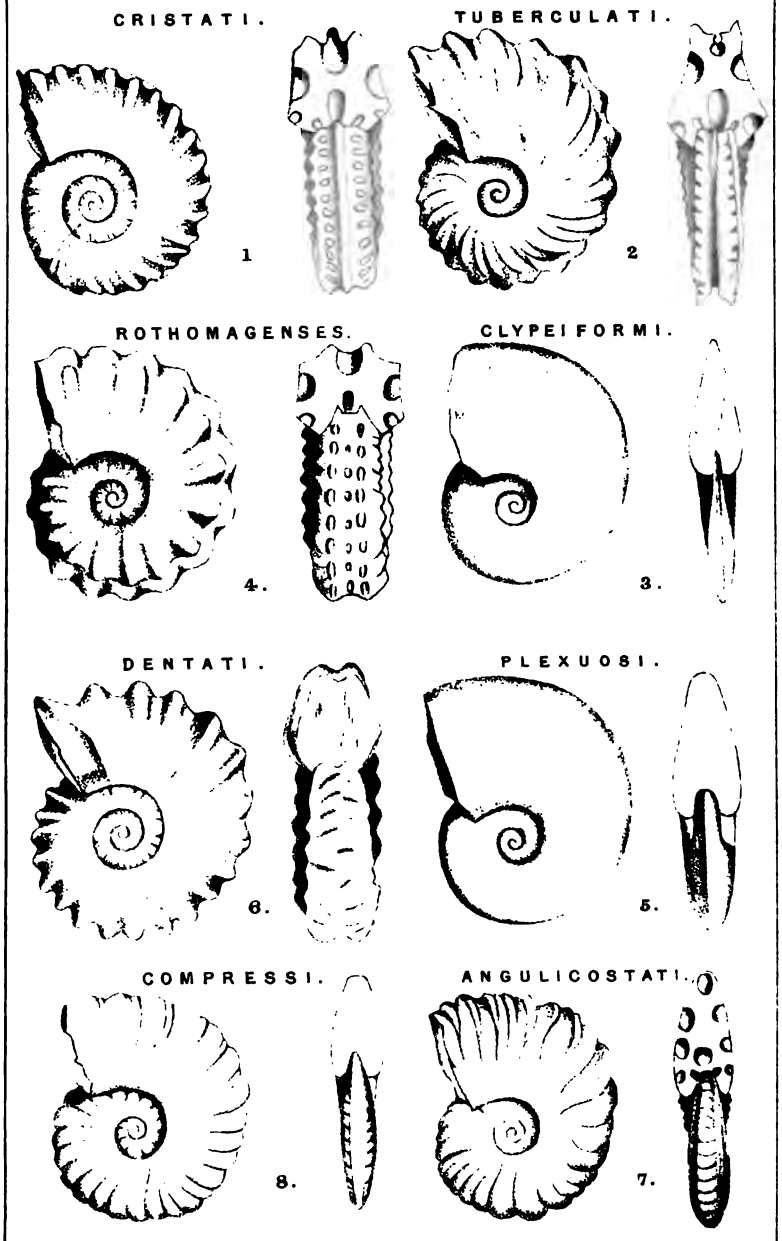
PLATE XXIII *C*.

CHARACTERISTIC CRETACEOUS AMMONITES.

1. *Ammonites* (*Schloenbachia*) *rostratus* (Sow.) Upper Greensand and Gault, Devizes and Folkestone.
   Group *Cristati*. Fam. *Schloenbachia*.
2. *Ammonites* (*Hoplites*) *lautus* (Sow.) Gault and Upper Greensand.
   Group *Tuberculati*. Fam. *Schloenbachia*.
3. *Ammonites clypeiformis* (Sow.) Upper Greensand.
   Group *Clypeiforme*. Fam. ?
4. *Ammonites* (*Acanthoceras*) *Rothomagensis*. Chalk Marl and Lower Chalk.
   Group *Rothomagenses*. Fam. *Stephanoceratites*.
5. *Ammonites* (*Cosmoceras*) *Leopoldianus*. Neocomian.
   Group *Flexuosi*. Fam. *Stephanoceratites*.
6. *Ammonites* (*Hoplites*) *interruptus* (Sow.)
   Group *Dentati*. Fam. *Stephanoceratites*.
7. *Ammonites* (*Hoplites*) *Deshayesii* (Leym.) Upper Neocomian.
   Group *Angulicostati*. Fam ?
8. *Ammonites catillus* (Sow.) Upper Greensand.
   Group *Compressi*. Fam. ?

PLATE XXIII.

CHARACTERISTIC CRETACEOUS AMMONITES.



developed. The type of the formation may be taken in Southern England or Northern France indifferently. In the latter country its extent on the surface is probably equal to the whole superficial area which it occupies elsewhere in Europe. In the European area two distinct areas of deposition can be recognised, each having its own character of sedimentation. The northern range includes Britain, and the Lowlands of Central Europe; while the southern region embraces the centre and southern part of France, the range of the Alps, and the eastern end of the basin of the Mediterranean. It encircles with a broad belt the basin of Paris, and passes off on the north-eastern side into Belgium, which whole country it probably underlies, though the Tertiary deposits conceal it, except along the sides of the Meuse. To the south of the central axis in France, it underlies the great basin of the Garonne, flanks the chain of the Pyrenees on both sides; it extends down the valley of the Rhone to the Mediterranean, occupying part of the north of Africa, and covering an enormous area in Asia. At Maestricht the upper beds of the Cretaceous formation have, in many respects, mineralogical and organic, a remarkable analogy to the lowest really marine Tertiary rocks in the vicinity. These beds, however, belong to the Cretaceous system, of which they may be considered the highest part at present known. The Chalk is observable north of the coal-measures of Elberfeld, as well as near Namur and Liege. The Cretaceous system most probably underlies the whole region of Northern Germany, from the point last mentioned north of the Oolite and Lias of Westphalia. The Neocomian is remarkably well exhibited with characteristic fossils in the romantic tract of Saxony, north of the Erzgebirge (there called *Quadersandstein*), as well as an upper calcareous portion supposed to be equivalent to the Chalk, and called *Plänerkalk*. North of the Carpathians, both Chalk and Greensand occur in long ranges of hills, passing from Poland by Lemberg into Podolia and the south of Russia. Eastwards in Russia the Cretaceous system covers many thousand square miles up to the latitude of the southern end of the Ural chain.

In Pomerania and Mecklenburg, and the Island of Rugen, cliffs of chalk occur with the usual fossils of England, and in Sweden they rest upon rocks of gneiss, and only in one instance, at Limhamm in Scania, upon rocks of the Jurassic era. In the north of Germany they appear, at intervals, near Luneburg, and on the borders of the Harz mountains (at Quedlinburg); and there seems no reason to doubt that the whole vast plain of Northern Germany, from the Rhine to the Vistula, rests upon the Cretaceous system. What remains of the Island of Heligoland consists of Neocomian strata.

The whole line of the Alps from the Salève to Vienna is bordered upon the northern side by rocks of the Cretaceous system, which are closely associated in character both with the Oolites beneath and with the Tertiaries which lie above. A similar observation applies to the south side of these mountains. Rocks of this era range down the Apennines, and occur abundantly in the Maritime Alps, there, as well as about Geneva, intimately associated with the Upper Jurassic beds. Deposits of this age also lie in old valleys of the Jura mountains,

which range in a north-eastern and south-western direction. The Pyrenees are bordered on both sides by Greensand and sandy and calcareous beds, containing with many Chalk fossils some of Tertiary types.

Over this extensive area the mineralogical characters of the system are tolerably uniform, except in the vicinity of the Alps, where it is entirely altered in its aspect, so as to be called *black chalk;* this, however, is really a portion of the Greensand group. Over all the region already mentioned in France, in Belgium, at all the points in Northern Germany, in Poland, in Russia, Pomerania, Denmark, and Sweden, the Chalk sustains its usual character and general appearance, and contains the same fauna as in Britain.

A series of rocks occupying so great a geographical distribution cannot fail to exhibit differences of type both lithologically and zoologically. They testify to a time when the Cretaceous seas covered the centre and much of the south of Europe, occupied Northern Africa, and more easterly still, the remote parts of Eastern Asia. That land under many conditions existed in this great extent of sea is evident, fully accounting for the diversity in the Fauna, and its Zonal distribution in now recognised areas.

Physical Features.—Through England the ranges of Chalk hills form a geographical feature even more important than those of the Jurassic series; for though in general not so elevated, they are less interrupted and more extensive, more uniform in composition, and therefore more characteristic in aspect. The Chalk hills form the first great ridge which is to be crossed from the eastern side of England. On approaching these broad hills from the level or gently undulated plains of the eastern counties, or the clay vales of the Jurassic system to the west, the country changes entirely. The streams run in smoothly sloping valleys, the hills rise with bold swells into long waving outlines, seldom broken by a tree, but often capped by great ancient tumuli. Plants, eminently characteristic of calcareous soil, force themselves on the attention; flints abound in the fields, chalk is cut through in the roads, the soil is thin, the herbage short, the surface dry, and we find ourselves in a new physical region.

This impression is confirmed when we observe more carefully the numerous undulations upon the surface of the "wolds;" for all these may be traced into connection, as so many ramifications of greater valleys, which themselves often unite, and pursue a considerable course without enclosing even the smallest rill, or showing even the mark of a watercourse.

The rain is absorbed as fast as it falls upon this dry surface, and sinks to considerable depths in the chalk, where it is stored up to supply the deep wells and the constant springs which issue at lower levels.

In a word, broad, swelling hills, smooth, winding, and often dry valleys, and a bare, dry, grassy surface, are the general features of the Chalk districts. This character of surface belongs to the Chalk wolds of Yorkshire, Lincolnshire, Norfolk, Suffolk, Berks, Wilts, Dorset, Hampshire, Surrey, Kent, and Sussex.

British Subdivisions.—The Cretaceous system of England has been divided into the following 8 groups or subdivisions:—

Upper Division.	1. Upper Chalk = Sénonien (D'Orb.)	
	2. Lower Chalk.	= Turonien (D'Orb.)
	3. Chalk Marl.	
	4. Chloritic Marl.	
	5. Upper Greensand or Cénomanien (D'Orb.)	
	6. Gault or Albien (D'Orb.)	
Lower Division.	7. Lower Greensand, Aptien, or Upper Neocomian.	
	8. Wealden.	

Table LXXXIII. (after Geikie) exhibits these divisions, with the relative Zones, arranged in descending order.

French Divisions.—In France, D'Orbigny has also divided the Cretaceous system into 8 divisions or stages:—

1. Danien,
2. Sénonien,
3. Turonien = Chalk without Flints,
4. Cénomanien = Upper Greensand,
5. Albien = Gault,
6. Aptien,
7. Urgonien,
8. Neocomien,

which correspond to those of Britain, as noticed above.[1]

Turonian (Lower White Chalk without Flints).—This extensive division of the White Chalk of England and the N.-West of France (both deposited in one basin) constitutes one of the best-known and remarkable deposits of the Upper Mesozoic rocks. From Flamborough Head, in Yorkshire, to Beachy Head, in Sussex, it is never lost save in the estuary of the Wash, where denudation and modern deposits have removed or obscured it. We have no evidence that the Chalk was accumulated or deposited over a sea-bed comparable in depth and condition to that of the Atlantic. The character of the microscopic fauna of the Chalk bears little relation to the deeply-seated Atlantic *Globigerina*-ooze or fine mud, except through the presence of the genus *Globigerina*. The other organic remains of the Chalk are at variance with the view that would associate them with such conditions as now exist on the deep floor of the Atlantic. The researches of M. Hébert[2] conclusively show that the Chalk was not deposited as one homogeneous and continuous deposit, nor has it remained undisturbed; but has undergone considerable oscillations and changes through emersion and denudation, as proved by the gaps that exist in the Upper Cretaceous series comprising the Anglo-Parisian basin. Most of the Cenomanian species had disappeared and were replaced by new forms.

The *three* Turonian Palæontological Zones of France are recognisable in England in the cliffs of the Kentish coast, and are characterised by the band of Gritty Chalk with *Inoceramus labiatus, Rhynchonella Cuvieri, Echinoconus subrotundus*, &c., succeeded by the massive flintless Chalk, in three series of 70, 90, and 60 feet respectively, covered by the thinly-developed "Chalk Rock." These correspond to the Zones in Cambridgeshire, both in position and fossil contents. The chief forms here are *Inoceramus Cuvieri, I. labiatus, Echinoconus subrotundus, Terebratulina gracilis*, and in the Upper Portion occurs *Holaster planus*.

[1] The Classification of D'Orbigny is the most simple and universally applicable. For the Systems of other French Geologists, MM. Hébert, Coquand, and Renevier, see chapter xlix.

[2] See "Rectif. et Additions au Mém., de MM. Hébert et Toucas sur la Géologie du bassin d'Uchaux," 1874; also "Classification du Terrain Crétacé supérieur." Hébert, 1875.

TABLE LXXXIII.—*Sub-Divisions of the British Cretaceous System.*

Stratigraphical Sub-Divisions.		Palæontological Zones.		
Upper Cretaceous.		*Danian not known in England.*		
Upper Chalk with Flints.	Chalk of Norwich	Horizon of *Belemnitella mucronata*	Zone of *Bel. mucronata.*	Senonian.
		„ *B. mucronata, B. quadrata*		
	Chalk of Margate	„ Sponges	Zone of *Marsupites ornatus.*	
	Chalk of Broadstairs	„ *Inoceramus mytiloides*	Zone of *Micraster cor-anguinum.*	
	Chalk of Dover		Zone of *M. cor-testudinarium.*	
Lower Chalk without Flints.	Hard nodular Chalk / Chalk Rock		Zone of *Holaster planus.*	Turonian.
	Chalk without Flint		Zone of *Terebratula gracilis.*	
	Nodular Chalk of Dover		Zone of *Inoceramus labiatus.*	
	Grey Chalk of Folkstone, &c.	Horizon of *Ammonites rhotomagensis*	Zone of *Belemnitella plena.*	Cenomanian.
		„ „ *varians*	Zone of *Holaster subglobosus.*	
	Totternhoe Stone	„ *Plocoscyphia mæandrina*		
Chalk Marl.	Chalk Marl			
Chloritic Marl.	Chloritic Marl, Cambridge Greensand		Zone of *Craie glauconieuse of France.*	
Upper Greensand.	Warminster Beds, &c.		Zone of *Pecten asper.*	
	Blackburn Beds, &c.		Zone of *Am. inflatus (rostratus).*	
Gault.	Upper		Zone of *Am. cristatus, A. auritus, A. lautus.*	Albian.
	Lower		Zone of *Hamites rotundus.*	
Lower Cretaceous.				
	Southern type.	*Northern type* (Marine).		
Neocomian Lower Greensand.	Fluviatile and in part marine.			Neocomian.
	Sands, Clays, Limestones, &c., in Kent, Surrey, Sussex, Hampshire.	*Upper* Neocomian, Speeton Clay of Yorkshire, upper, 150 feet.	Upper. *Perna Mulettii, Exogyra sinuata,* &c.	
Wealden.	Weald Clay.	*Middle* Neocomian, Speeton Clay next, 150 feet, and the Tealby Beds.	Middle. Zone of *Pecten cinctus, Ancyloceras* Beds.	
	Hastings Sands and Clays passing down into Purbeck Beds.	*Lower* Neocomian, Speeton Clay next, 200 feet.	Lower. Zone of *Am. Speetonensis.*	
			„ *Am. noricus.*	
			„ *Am. astierianus.*	

(*After* Geikie.)

Senonian (*Upper Chalk with Flints*).—This massive series has been generally regarded by English geologists as a single formation of uniform lithological character, and as possessing the same fossils throughout. Mr. Whitaker and Mr. Jukes-Brown have both shown that distinct physical as well as zoological Zones occur throughout our English Upper Chalk,[1] and MM. Hébert and Barrois have proved the same for the Upper Chalk of the Paris basin.

The Chalk of Kent exhibits two Zones which, united, are of great thickness. The lower stage contains *Micraster cor-testudinarium;* the upper, *Micraster coranguinum.* These beds contain the fine Cidaridæ and Diademadæ, which abound in places in the Chalk of Kent and Surrey, illustrated by *Cidaris clavigera, C. sceptrifera, Cyphosoma Kœnigii,* and *C. magnificum,* associated with *Echinoconus conicus, Epiaster gibbus,* and *Inoceramus involutus.*

The *Marsupite* Zone attains a thickness of about 80 feet in the Isle of Thanet, and the same beds in the Hampshire basin are 400 feet thick. These Crinoidea are *Marsupites ornatus, M. Milleri,* and *Bourgueticrinus ellipticus,* with *Micraster coranguinum, Echinoconus gibbus, E. conicus, Cidaris clavigera, C. sceptrifera, Belemnites verus,* and *Ammonites leptophyllus,* with many other species, especially *Lima* (*Spondylus*) *spinosus* and *Terebratula semiglobosa.*

The highest or Norfolk Chalk does not occur to its full extent south of Bury St. Edmonds. It constitutes the Zone of *Belemnitella mucronata,* so well developed in Northern Europe. Among the fossils of the Norwich Chalk are the corals *Trochosmilia laxa* and *Parasmilia centralis.* The Echinoidea are *Salenia geometrica* and *Echinocorys ovatus,* accompanied by *Terebratula carnea, T. obesa, Belemnitella mucronata* and *B. quadrata.*

CHAPTER XLV.

LOWER CRETACEOUS STRATA: THE WEALDEN FORMATION.

BETWEEN the close of the Jurassic series and the Gault, there occurs, both in this country and in many parts of Europe, an extensive series of deposits, to which, from their great development in the neighbourhood of Neufchatel (Neocomum), has been given the name *Neocomian.* This series is represented in England by two distinct types of strata (a Northern and a Southern).

A. Types of Neocomian Strata (Estuarine).—In the Southern counties there occurs a great succession of fluviatile and estuarine sands and clays, termed the *Wealden.* These estuarine beds pass up into a marine group, known in England as the Lower Greensand, in which many of the characteristic European Neocomian species occur. We must, therefore, admit the fluviatile or estuarine equivalency of the greater part of the Wealden with the whole of the Continental Neocomians; while it would appear that the Lower Greensand (so called) of the South of England represents the later marginal accumulations of the Neocomian sea, which took the place of the Wealden estuary.

B. Marine.—The second or marine type occurs in the tract of

[1] Whitaker, Mem. Geol. Survey of Great Britain, vol. iv., pt. 1. Jukes-Brown, Geol. Mag. decade 2, vol. vii., 1880.

country stretching from Lincolnshire to Yorkshire, and constitutes the Western extension of the Cretaceous series of the European basin.[1]

The Wealden Formation.

Until the appearance of Mantell's works on the geology of Sussex, the peculiar relations of the great thickness of sandstones and clays of the interior of Kent, Sussex, and Hampshire were misunderstood. The immense mass of the Wealden strata is altogether of a peculiar type, and interpolated amidst marine formations, as a local estuarine series, of which only very faint traces can be obtained in other parts of England.

Mantell's publications, followed by many other writings, have clearly shown that the true stratigraphical place of the Wealden in time is *below* the Neocomian or Lower Greensand, and immediately *above* or succeeding the Purbeck Limestones, which overlie the Portland Oolite.

The only places in England where analogous beds are known to occur outside the Wealden area, are at the back or south side of the Isle of Wight, in the Isle of Purbeck, along the south side of the Dorset Downs, and near Oxford.

Weald Groups.—The Wealden is naturally divided into two groups, which give distinct physical features to the counties or area which they occupy; and if to these we add the Purbeck Limestones below, we have the following order of succession:—

Upper group. Weald clay.	Pale blue clay, of considerable but variable thickness, having in the upper part septaria of argillaceous ironstone, and in the lower part beds of the shelly limestone called Sussex marble.
Middle group. Hastings sand.	Fawn-coloured sand and friable sandstone. (Horsham beds.) Calciferous sandstones, alternating with friable and conglomerate grits, resting on blue clay. (Tilgate beds.) White sand and friable sandstone, alternating with clay. (Worth sandstone.) Bluish-grey limestone, alternating with blue clay and sandstone shale, and some beds of calciferous sandstone. (Ashburnham beds.)
Lower group.	The Purbeck beds, consisting of shelly limestones alternating with clay.

The Weald Clay forms one general valley, most conspicuous on the northern side, between the elevated central ridges of the Hastings sands and the chalk downs of Kent, Surrey, Hampshire, and Sussex, from Hythe by Tunbridge, Hartingcombe, and Hailsham, to Pevensey.

The Hastings Sands are distinguished by forming a central axis of elevation along what is called the Forest ridge, by Battle, Crowborough, and Tilgate Forest to Horsham; Crowborough, the highest point, is 804 feet above the sea. The general East and West axis of elevation is confused or affected by a number of local disturbances, and is, moreover, so broad a ridge that its character is often overlooked. Doubtless the Chalk of the northern and southern escarpments once extended over all the Wealden area, but has been subsequently removed by denudation.[2]

[1] *Vide* Prof. Judd: Q. Jour. Geol. Soc., vols. xxvi., xxvii.; *ib.* Geol. Mag. vol. vii.

[2] See Topley and C. Le Neve Foster on the Superficial Deposits of the Medway,

Fresh-Water Origin of the Weald.—The evidence upon which it is now admitted that the Wealden series was a fresh-water or estuarine deposit, is founded upon our knowledge of the organic remains, and this admits of three general observations.

First. There is in all the Wealden strata, whether sandy, argillaceous, or calcareous, an almost entire absence of marine genera of mollusca.

Secondly. What shells do occur are fresh-water genera, and this evidence bears upon all the groups.

Thirdly. The plants which abound in this middle group are of terrestrial, or marshy, and not of marine origin, and the Saurian remains also indicate terrestrial, littoral, or marshy life conditions.

Range.—The Wealden formation occupies an extensive and well-defined geographical area in the south-east of England; its boundary is the chalk escarpment which, commencing near Dover, passes through the counties of Hants, Surrey, Kent, and Sussex, to the sea at Beachy Head. This oval-shaped area is termed the Weald. Wealden strata also occur in Dorsetshire and the Isle of Wight. Fresh-water strata of Wealden age were determined by Professor Phillips at the base of the Neocomian near Oxford. In the counties of Kent and Sussex the Fluviatile and Estuarine Wealden is surmounted by a group of marine strata (the Upper Neocomian). In the south of England these depositions of fresh-water strata commenced towards the close of the Jurassic period, when the Purbeck strata were laid down; and only through great geographical changes in that area and northern France did marine sedimentation take place.

Two great divisions (an upper and lower) have been established to receive these fresh-water and estuarine strata—

A. The upper, comprising the Weald clay, 1000 feet thick.

B. The lower, embracing the Hastings sands or Hastings beds, which are composed of three chief series:—

1. The Tunbridge Wells Sand,
2. The Wadhurst Clay,
3. The Ashdown Sand,

possessing a united thickness of about 1500 feet.[1]

A.—The Wealden and Purbeck beds, through their sedimentation, represent the Delta or lagoon deposits of an immense river or broad estuary, which in size or extent may have rivalled that of the Ganges, Mississippi, or the Amazon. The deltoid area, in which the remains of the huge Deinosaurian reptiles occur, extends in England from east to west 200 miles, and from north to south 100 miles; hence the Delta in our area could not have been less than 20,000 square miles. Its original extent must have been much greater than its present visible area, this having suffered extensive denudation, as well as being now concealed by newer formations.

and remarks on the Denudation of the Weald, Quart. Jour. Geol. Soc., vol. xxi.; and W. Topley on the Lower Cretaceous beds of the Bas-Boulonnais, with notes on the English equivalents, Q. Jour. Geol. Soc., vol. xxiv.

[1] Consult for every particular the Mem. of the Geol. Survey of Great Britain, 1875, Geology of the Weald, by W. Topley, F.G.S., with Lists of Fossils, by R. Etheridge.

TABLE LXXXIV.—Geological Formations of the Wealden Area.

The subjoined tabular form exhibits the strata exposed within the Wealden area, below the Atherfield or Upper Neocomian Series: [1]—

Marine.	Upper Cretaceous.			Upper Greensand			
				Gault.			
		Upper Neocomian.		Lower Greensand, 70 to 500 feet.	Folkstone beds. Sandgate beds. Hythe beds. Atherfield Clay.	These 4 divisions represent the Upper Neocomian Series of the Continent.	
Fluvio-marine Punfield formation.	Lower Cretaceous.	Lower Neocomian.	Wealden beds.	Weald Clay		. . . . .	400 to 1000.
				Hastings beds	3. Tunbridge Wells Sand, 160 to 380 feet.	Upper Tunbridge Sand (with Cuckfield Clay).	100 to 200.
						Lower Tunbridge Wells Sand.	30 to 130.
					2. Wadhurst Clay	. . . .	100 to 180.
					1. Ashdown Sand.	Ashdown Sand . .	150.
						Fairlight Clays . .	360.
Fluvio-marine.		Oolite		Purbeck beds.	Ashburnham beds	. . . . .	400.

Of the total number of fossils from the "Lower Greensand" or Upper Neocomian (upwards of 400), only 65 (or 16 per cent.) pass to the Upper Cretaceous (chiefly to the Gault). This palæontological break with unconformity between the Lower Greensand and the Gault in the south of England, and the top of the Speeton clay and succeeding Red chalk or Hunstanton limestone in Norfolk, clearly shows that a definite boundary-line exists between the lower and upper parts of the Cretaceous system of England.

Hastings Beds.

1. Ashdown Sand.—This division occupies a large area of the higher part of the Hastings sand.
2. Wadhurst Clay.—Consisting almost entirely of clay and shale, nodules, and occasional bands of clay ironstone, the chief source of the iron ore of the Old Wealden furnaces.
3. The Tunbridge Wells Sand.—A clay bed occurs near the base termed the "*Grinstead Clay*," and the sands above and below this clay are known as the "Upper and Lower Tunbridge Wells Sand."

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[1] *Vide* Mr. Topley's Memoir upon the Geology of the Weald (Mem. Geol. Survey, vol. for 1875).

PLATE XXIV.

PURBECK AND WEALDEN FOSSILS.

1. *Unio valdensis* (Mant.) Hastings Sand, &c. Wealden, Isle of Wight, Hastings.
2. *Cyrena media* (Sow.) Weald Clay. Kent, Surrey, Sussex.
3. *Cypridea valdensis* (Sow.) Weald Clay. Isle of Wight, Tunbridge Wells, Dorset.
4. *Vicarya lujani* (Du Verneuil). Punfield beds and Upper Neocomian. Isle of Wight, and Punfield.
5. Vertical section of same, showing ridges.
6. *Cypridea tuberculata* (Sow.) Upper Purbeck beds.
7. *Do. fasciculata.* Middle Purbeck beds.
8. *Modiola Fittoni.* Purbeck beds.
9. *Archæoniscus Brodiei* (M. Edw.) Purbeck. Vale of Wardour.
10. *Cidaris Purbeckensis* (Forbes). Middle Purbeck (Cinder bed).

PLATE XXIV.

PURBECK AND WEALDEN FOSSILS.

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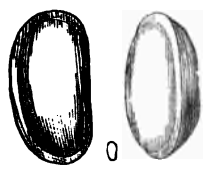

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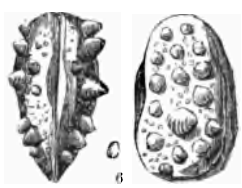

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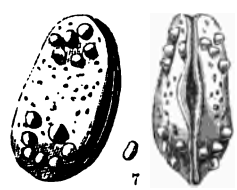

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B.—**The Lower or Hastings Series** is divided into 6 sub-formations :—

6. Upper Tunbridge Wells Sand.	Tunbridge Wells beds.
5. Grinstead Clay.	
4. Lower Tunbridge Wells Sand.	
3. Wadhurst Clay (with iron ore).	
2. Ashdown Sands.	
1. Ashburnham beds.	

Weald Clay.—This is the highest division of the Wealden beds. West of Horsham it attains a thickness of nearly 1000 feet, but thins away towards the east. The greater part of this division consists of clay and shale, and some bands of shelly limestone.

Fairlight Clays.—These clays occur both on the east and west sides of Hastings, and are composed of alternations of clay and sandstone ; much false bedding occurs in them. They attain a thickness of 360 feet.

Ashdown Sand.—"This division occupies some of the highest ground of the country, owing to the anticlinal fold ; it also occurs at the lowest levels, being exposed by denudation along the valleys. East of Hastings it is 150 feet thick." The old town of Hastings is entirely built on the Ashdown Sand, whilst St. Leonards mainly stands upon Tunbridge Wells sand. The top of the east cliff from Hastings to Fairlight is composed of Wadhurst clay (Topley, *loc. cit.*)

Wadhurst Clay.—A division of the Hastings beds consisting of alternations of clays, shale, and sand-rock, also fossiliferous limestones and clay ironstone. Associated with the ironstone are layers of thin limestones, largely composed of *Cyrenæ* and *Paludinæ*. The clay is rich in fossils (individuals rather than species). Amongst others the following occur :—

PLANTÆ.—*Endogenites erosa, Equisetites Lyellii, Lignite,* &c.

CRUSTACEA.—*Cypridea tuberculata, C. valdensis* and C. sp., with *Estheria membranacea.*

MOLLUSCA.—*Paludina fluviorum, P. sussexensis, Cyrena parva, C. angulata, Unio* sp.

FISH and REPTILIA.—*Lepidotus mantelli,* bones and teeth of *Crocodilia* and *Iguanodon.* On Tetham Hill one and a half mile S.E. of Battle, in the Black Horse Quarry, occurs the bone bed from which great quantities of Vertebrate remains have been obtained. Very few are perfect. The following occur :—*Megalosaurus, Iguanodon, Goniopholis, Teleosaurus, Leiodon, Plesiosaurus, Chelone, Pterodactylus, Pycnodus,* and *Hybodus.*

The Wadhurst clay occupies a considerable area in the Cranbrook and Tunbridge Wells district ; calcareous sandstone (Tilgate stone) is the most valuable product, now that the argillaceous or clay ironstones are no longer obtained.

Tunbridge Wells Sand.—On the N.E. of Hastings the great mass of sands around Peasemarsh and Beckley belongs to the Tunbridge Wells series. A subordinate bed of clay (*the Grinstead clay*) divides the Tunbridge Wells sand into two divisions, upper and lower. The total

thickness of this division at Goudhurst is about 150 feet; near Tunbridge Wells 180 feet.—Topley, *loc. cit.*, pp. 45–79.[1]

The Wadhurst Clay in the E. Grinstead area near Uckfield is 120 feet thick, and between E. Grinstead and Tunbridge Wells much the same.

Grinstead Clay closely resembles the Wadhurst Clay; at East Grinstead it is about 40 feet thick. This clay has an important bearing upon the stratigraphical relations of the beds above and below. At the N. end of Balcombe tunnel a fine section of this division is exposed. *Paludinæ* and *Cyrena media* occur in some localities.

Cuckfield District.—This area is of classic interest, owing to the circumstance that most of Dr. Mantell's Saurian remains were obtained here.[2] They were fragmentary, but the following have long been known:—

Cetiosaurus brevis, Pelorosaurus (Cetiosaurus) Conybeari, Platemys Dixoni, P. Mantellii, Pœcilopleuron Bucklandi, Regnosaurus Northamptoni, Streptospondylus major, Chelone Mantellii.[3]

Weald Clay (Upper Series).

History.—As the name implies, this formation is nearly all composed of clay and shale, and varies from 400 to 1000 feet in thickness. Beds of limestone here and there occur, and can be traced continuously for considerable distances. Some Limestones are composed entirely of the fresh-water shell *Paludina*.

In thickness the Weald clay varies considerably. It appears to be thickest in the meridian of Leith Hill;[4] here probably from 900 to 1000 feet, while about Tunbridge and Maidstown it may be 600 feet.[5] It probably becomes thinner to the east, and at Hythe may not be more than 350 feet.

On the opposite side of the English Channel, in the Lower Boulonnais, the Weald clay has probably completely disappeared (Topley). Near the top of the Weald clay at Hythe there occurs an intermixture of marine and fresh-water shells.

Fauna.—Bands of *Ostrea distorta* are associated with *Cyrenæ* and other fossils characteristic of the Wealden beds, viz., *Cypris Valdensis, C. tuberculata, C. spinigera*, and *Paludina fluviorum*. Here also a distinct passage into the Atherfield clay above has been noted, thus the junction between the marine and fresh-water formations can be determined.[6] At Haslemere the upper Wealden beds contain *Mela-*

[1] Mr. Topley devotes 34 pages to the Hastings sand group (*loc. cit.*) Full sections are given, and a complete history of the entire Wealden stratigraphy, from p. 30–111.

[2] The exact position of the quarries cannot always be determined, as Mantell spoke of the district as "Tilgate Forest," not specifying particular places.

[3] See Mantell's "Fossils of the British Museum"; also "Wonders of Geology," and "Medals of Creation."

[4] The top of the Weald clay seems to attain its maximum height at Leith Hill, owing, probably, to its greater thickness there.

[5] *Vide* Topley, *loc. cit.*, p. 96–7.

[6] At Haslemere both the Wealden and Neocomian (Atherfield clay) can be seen, the latter being 60 feet thick, with the Hythe beds above and the Weald clay below.

nopsis, *Cyrena*, and *Cypris*; and worm or annelid burrows mark the *junction of the two formations*, being followed by *Panopæa* standing vertically in the silty mud, as the living species do now.

Perna and *Nautilus* with other mollusca occur just above the junction line, agreeing in every particular with the sections shown in the Isle of Wight. The more important fossils occurring at Haslemere are—*Nautilus pseudo-elegans* or *radiatus*, *Arca Raulini*, *Exogyra sinuata*, *Gervillia anceps*, *G. alæformis*, *Panopæa* (*Myacites*) *plicatus*, var., *mandibula* (as living), *Perna quadrata*, *Pinna tetragona*, *Trigonia caudata*, *T. dædalea*, and the highly characteristic Coral *Holocystis elegans*. Every species here belongs to the Atherfield beds (or Upper Neocomian).[1]

Horsham Bed.—The horizon of this bed is about 120 feet above the base of the Wealden; it is a calcareous sandstone, often ripple-marked, and is much used for building, paving, and roofing.

a. **Paludina Limestone or Marble** (*Small Paludina Marble*) seen at Idenbourn, Frittenden, Maplehurst Farm, Staplehurst, and also at Crowhurst, some miles to the west.

b. **Paludina Limestone** (*Large Paludina Marble. P. Sussexensis*, Mant.).—This remarkable bed is not known on the north of the Weald.[2] It is, or was, worked near Plaistow and south-east of Chiddingfold.

c. **Paludina Limestone** (*Paludina Marble. 'P. fluviorum*, Sow.).—This is the most constant and important bed in the Weald Clay. Along its outcrop it has received various names, as Bethersden Marble, Petworth Marble, Sussex Marble, &c. This bed (renowned in the annals and history of church architecture) occurs about 100 feet below the top of the Weald Clay.[3]

The Punfield Formation.

The deposition of the Wealden strata of the south of England commenced before the close of the Jurassic period; it continued during the whole of the Tithonian,[4] or part of the Wealden and the Lower and Middle Neocomian epochs.

The deposition of the Wealden strata did not extend to the north of France until the latter part of the period. The Wealden of Northern Germany is the deposit of a different river and its delta, from that which formed the Wealden of England and France; and the period of its formation, while it commenced at the same epoch, was of shorter duration, coming to a conclusion before the end of the deposition of the Lower Neocomian.

At the *base* of the great fresh-water system of the Wealden, there

[1] These species are given here to show the passage from the fresh-water Weald Clay into the marine Atherfield series, and as proof of the great depression that must have taken place to allow of so characteristic a marine fauna succeeding at once the fresh-water series.

[2] This is the true Sussex marble. The "*thickest* (12 inches) *and finest bed of Sussex Marble*" (Martin).

[3] For History and Geographical distribution of this Paludina Limestone, see Mr. Topley's description (Mem. Geol. Surv., *loc. cit.* pp. 107–8). The entire chapter on the Weald Clay should be read, embracing pp. 96–111.

[4] Assigned by the French geologists to the commencement of the Cretaceous system. The Austrian geologists refer the Tithonian beds to the Upper Jurassic period, or top of the Alpine Jurassic series.

occurs a series of beds with fluvio-marine characters, constituting the "*Purbeck Formation.*"

At the *top* of the Wealden there occurs another series of strata of similar character, which Professor Judd has named the "*Punfield Formation.*"

The Purbeck group, through its stratigraphical relations, and the fossil contents of its marine beds, appears to be closely related to the Jurassic system. The "Punfield Formation" is on similar evidence referable to the lower portion of the *Neocomian system.* In both the Purbeck and Punfield we have evidence of the alternation of fresh-water, brackish-water, and marine *conditions.* They are alternating marine and fresh-water beds which occur near the junction of the Weald and Atherfield Clays.

These several formations occur in unbroken sequence as follows :—

Upper Neocomian (Lower Greensand) .	*Marine.*
Punfield formation	*Fluvio-marine.*
Wealden	*Fresh water.*
Purbeck formation	*Fluvio-marine.*
Upper Oolite	*Marine.*

I. Immediately below the Lower Greensand or Upper Neocomian at Punfield Cove, there occurs a series of fluvio-marine beds, now included in the Punfield formation by Professor Judd.[1] The beds are divided into three sections or groups of strata :—

1. Upper part, finely laminated cypridiferous shales, resembling those occurring on the same horizon in the Isle of Wight.
2. Ferruginous sands and clays, about 150 feet thick, containing marine shells. Dwarfed forms of *Exogyra sinuata* and *E. Boussingaultii* occur. No Ammonites are known in this series, but doubtful *Vicarya.* The oyster beds have yielded *Exogyra sinuata, E. Boussingaultii, Cardium subhillanum, Corbula striatula,* and *Anomia lævigata* (abundant).
3. **The Marine Band.**—This possesses a remarkable marine fauna. At Punfield Cove it is a marked feature, although the bed is only 21 inches in thickness. Besides the shells that occur in the Ostrea beds above, we find here a large and well-marked assemblage of Upper Neocomian forms, including *Ammo. Deshayesii,* forms of *Vicarya, Trochus, Actæon, Orthostoma, Pholadomya,* &c.

Fauna.—The lowest portion of the marine band contains a hard, shelly, ferruginous limestone, which yields the chief mass of the fossils. Thirty-two genera and 40 species have been obtained. Amongst them are many significant and characteristic species. *Am. Deshayesii, Vicarya pizcuetana, V. Lujani* and *V. Pradoi, Cerithium vilanovæ, Turritella Tournali, Pleurotoma Utrillasi, Actæon esquerræ, E. pradoana, Neritopsis minima, Orthostoma Verneuili, Plicatula asperrima, Modiola griffreana, Arca cymodoce, Cardium subhillanum, C. impressum, Isocardia nasuta, Pholadomya* sp., and *Pholadomya semicostata,* &c., with much wood and carbonaceous matter. Nearly all the above species are new to Britain.[2]

II. **Worborrow Bay.**—In the cliffs at Worborrow Bay, 11 miles west of Swanage Bay, there occurs another exposure of the Punfield series, about 60 feet thick. No trace is found of the oyster bands or limestone beds, the whole thickness being composed of interlaminated clays and bands. *Ostrea, Cardium, Corbula,* and *Cerithium* occur in the middle portion.

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[1] On the Punfield Formation, by J. W. Judd, F.R.S., Q. J. Geol. Soc., vol. xxvii. p. 207; Comparative sections between Swanage and the Isle of Wight, p. 213.

[2] Out of 70 species occurring in the same beds in eastern Spain, we have between 30 and 40 in the Punfield deposit.

Isle of Wight.

Brixton Bay, a little to the west of Atherfield Point, is the clearest exhibition of the representative of the Punfield formation. The Punfield strata here occur between Atherfield Point and Barnes High. Their junction with the overlying Perna beds of the Upper Neocomian was noticed by Fitton in 1847.[1] Professor Judd divides the Punfield strata of the Isle of Wight into two groups—

A. *The Cowleaze Series.*
B. *The Barnes Series.*

A. The thickness of the *Cowleaze beds* is about 180 feet; at Cowleaze Chine about 100 feet of the lower portion are seen in one section. *Exogyra sinuata*, *Modiola*, *Cardium*, and *Cerithium* are the known mollusca.

B. **The Barnes Series.**—Chiefly arenaceous beds with bands of clay. They rest upon the variegated strata of the Wealden. *Cyrena* and *Unio* occur in the top band of sandstone. *Trigoniæ*, *Cardium*, and *Ostrea*, with *Hypsolophodon* and other reptilian bones, were obtained from the Barnes Punfield series.

Compton Bay.—The *Cowleaze series* with the *Cyrena* and *Paludina* limestones, "beef" and "cinder" beds, are well exposed. *Panopæa plicata*, *Ostrea* 2 sp., *Serpulæ*, and *Fish scales* occur in the marine bands. The *Barnes series*, about 50 feet thick, presents its usual sandy character. Plants and insects occur, but *no marine* bands were observed.

Sandown Bay.—On the N.-E. side of the bay, below the Red Cliff, the Punfield beds are well exposed. The junction of the Upper Neocomian and Wealden is exhibited in the cliff section, showing the Atherfield clay, and the Perna beds below, composed of brown sandstones, and rich in fossils. The blue and dark paper shales of the Weald clay, down to the oyster-bands and dark-blue laminated shales and sandstones, in all 60 feet, are a marked feature.

Unconformity between the Cretaceous and Neocomian.—The late Captain Ibbetson first clearly demonstrated the existence of unconformity between the Upper or Cretaceous proper, and the Lower or Neocomian in the south of England.[2] While the Chalk, Upper Greensand, and Gault beds in the Isle of Wight are nearly horizontal, the Neocomian and Wealden dip to the E. at a low angle. This being the case, true Cretaceous beds overlap in succession all the beds of the Oolite and Lias, resting in Devonshire on the Trias. A similar condition or overlap has been demonstrated in Yorkshire by Phillips and Wm. Smith; and Prof. Judd shows that the same phenomenon occurs in Lincolnshire. The labours of the Geological Survey again have proved that a similar overlap of the true Cretaceous beds occurs all round the Weald, and throughout the Midland area as far as the survey has been carried. The same physical feature is exhibited between the Cretaceous and Neocomian strata of France and Switzerland.[3]

[1] Q. Jour. Geol. Soc., vol. iii.
[2] Q. Jour. Geol. Soc. vol. iii. p. 315.
[3] *Vide* Prof. Judd on the Punfield formation. Q. Jour. Geol. Soc., vol. xxvii.

Foreign Equivalents of the Punfield Formation.

1. *"Urgonien" and "Rhodanien" of France and Switzerland, &c.*—The careful labours of Pictet, Renevier, and others have long determined that the strata known as "*Lower Greensand*" in England represent or are correlated with the "*Aptien*" or Upper division of the great Neocomian system of the Continental authors, and this has been generally accepted by physical geologists and palæontologists. The "*Urgonien*"—with its white Limestones, Rudistes, and corals, which are so widely distributed in Southern Europe—has everywhere been recognised, both stratigraphically and zoologically, as constituting the middle portion of the Neocomian system.

M. Renevier of Lausanne in 1854[1] showed that between the *Aptien* (Lower Greensand, upper part), and "*Urgonien*" (Upper Neocomian, Pict.), there existed another series of beds, with a distinctive fauna, named by him "*Rhodanien*" (our Atherfield Clay, Perna beds, and Cracker beds of the Isle of Wight), equivalent to the "*Couche rouge*" of Vassy, Dept. of the Haute-Marne.

Ammonites Deshayesii, which occurs in the marine band of Punfield, is a widely distributed species in space, but has a restricted range in time, or in vertical distribution, abounding in the higher portions of the Neocomian, but unknown in the "*Urgonien*" or any lower beds.

Vicarya Lujani and many other of the Punfield mollusca are characteristic Rhodanien or Upper Neocomian forms.[2]

Spain.—It is in the Spanish peninsula that we must seek for close analogy with the Punfield formation. MM. Vilanova, de Verneuil, Collomb, de Lorière, and Coquand have all made known to us their researches through these beds. M. Coquand, in his valuable memoir, describes the principal exposures[3] and history of the deposits in the ancient kingdoms of Arragon and Valencia in Spain. Prof. Judd has ably epitomised the main features of the labours of the above authors in his paper upon the Punfield formation.[4] He also gives reasons for his conclusions, and for considering the beds worthy of an independent position in the British strata.[5]

[1] Bull. de la Soc. Géol. de France, 2nd sér., tome xii.

[2] Prof. Judd regards the "Perna beds" as the base of the Upper Neocomian, and the Punfield beds as the highest part of the Middle Neocomian.

[3] H. Coquand: Mém. de l'Étage Aptien de l'Espagne, 1865; De Verneuil et Collomb: Bull. Soc. Géol. de France, 2nd sér. tome x.; *ib.* Carte Géologique de l'Espagne et du Portugal, Paris, 1864.

[4] On the Punfield formations, Q. Jour. Geol. Soc., vol. xxvii., p. 223–25.

[5] The Punfield fauna is included in the Wealden Table under the head "Punfield beds."

TABLE LXXXV.—*Wealden Fauna Enumerated through Six Classes.*[1]

	Classes.	Genera.	Species.	Hastings Sand.	Weald Clay.	Punfield Beds.
...	Plantæ . . .	22	32	12/31	4/4	...
...	Protozoa . .	...	...	...	...	...
...	Rhizopoda . .	...	...	...	...	...
...	Actinozoa . .	...	...	...	...	...
...	Echinodermata .	...	...	...	...	...
...	Annelida . .	...	...	...	...	...
1/5	Crustacea . .	2	8	2/6	2/2	...
...	Polyzoa . .	...	...	...	...	...
...	Insecta? . .	...	...	...	...	...
...	Brachiopoda . .	...	...	...	...	...
1/4	Pelecypoda . .	16	38	...	1/2	4/6
1/4	Gasteropoda . .	16	29	5/5	2/2	1/18
...	Cephalopoda .	1	1	...	...	1/1
...	Pisces . . .	9	15	9/15	4/4	...
...	Reptilia . .	27	38	32/37	4/5	...
...	Mammalia . .	None.		...	...	...
5/14		93	161	67/114	23/40	27/38

TABLE LXXXVI.—*Organic Remains of the Wealden Strata, including the Punfield Series.*[2]

(See Plate XXIV., figs. 1, 2, 3, 4, and 5.)

PLANTÆ.	No. of Species.
Abietites.	1
Alethopteris	1
Araucaria	1
Araucarites	1
Bennettites	2
Bucklandia	2
Carpolithes	2
Chara	1
Clathraria	1
Cycadeostrobus	4
Endogenites	1
Equisetites	2
Fittonia	1
Hymenopteris	1
Lonchopteris	1
Pinites	1
Oleandridium	1
Pecopteris	1
Pterophyllum	1
Sphenopteris	4
Thuytes	1
Zamiostrobus	1
	32
CRUSTACEA.	
Cypridæa	6
Estheria	2
	8
MOLLUSCA.	
Pelecypoda.	
Anomia	2
Plicatula	1

[1] The remaining 9 classes are not represented in Britain.

[2] No Wealden species pass to higher strata.

	No. of Species.
Arca	1
Cardium	2
Corbula	2
Cyrena	7
Isocardia	1
Leda	1
Modiola	1
Mytilus	1
Ostrea	2
Perna	1
Pholadomya	2
Psammobia	1
Tellina	1
Unio	12
	38

GASTEROPODA.

Actæon	2
Acteonella	1
Bulla	1
Cerithium	3
Fusus	1
Melanopsis	2
Natica	2
Neritina	1
Neritopsis	1
Orthostoma	1
Paludina	7
Pleurotoma	1
Trochus	1
Turritella	1
Tornatella	1
Vicarya	3
	29

CEPHALOPODA.

Ammonites	1

PISCES.

Placoidei.

Acrodus	1
Asteracanthus	1
Hybodus	6
Meristodon	1
Oxyrhina	1

Ganoidei.

Æchmodus	1
Gyrodus	1
Lepidotus	2
Pycnodus	1
	15

REPTILIA.

Deinosauria.

Chondrosteosaurus	2
Calamospondylus	1
Hypsilophodon	1
Hylæosaurus	2
Iguanodon	3
Megalosaurus	1
Polacanthus	1
Phytosaurus	1
Regnosaurus	1
Vectisaurus	1
Ornithopsis	1
Sphenospondylus	1

Crocodilia.

Bothriospondylus	2
Cetiosaurus	2
Crocodilus	1
Goniopholis	1
Pelorosaurus	2
Pœcilopleuron	1
Streptospondylus	1
Suchosaurus	1
Thecospondylus	1

Enaliosauria.

Plesiosaurus	1

Chelonidæ.

Chelone	2
Tretosternon	1
Platemys	3

Pterosauria.

Coloborhynchus	1
Pterodactylus	2
	38

Mammalia none.

CHAPTER XLVI.

NEOCOMIAN STRATA.

DISTINCT unconformity exists between the Cretaceous rocks proper and the Neocomian series, all below the Gault or "Albien" beds being unconformable to the overlying series.

In consequence of this, the Chalk overlaps all the Neocomian and Jurassic beds in succession down to the Lias.[1] "At Speeton Cliff upwards of 500 feet of Neocomian clays are exposed; while of the *Upper Neocomian clays* (150 feet thick), with the Cement beds and Atherfield fauna, no traces are discoverable inland; they are completely covered by the great drift-clay deposits of the Vale of Pickering."

So with the *Middle Neocomian* and its well-defined fauna, typified by the gigantic shell, *Pecten cinctus*, and bands with *Ancyloceri*. The *Lower Neocomian* is traced inland at Reighton Gill and West Heslerton and Knapton, the latter place 40 miles distant.

The Speeton Clay, Yorkshire.

The marine type of the Neocomian strata of England is extensively exposed in the cliffs near Filey (Yorkshire), where it has long been known as the "*Speeton clay.*" The argillaceous deposits of the Bay between Filey Brig and Speeton Gap belong both to the Jurassic and the Neocomian series, the Portlandian, Kimmeridgian, and Speeton Clay or Neocomian beds being all present, between the above-named two points.

Speeton Cliffs.—This cliff-range extends about 1000 yards, varying in height from 150 to 220 feet. It is divided into three well-marked projecting prominences.[2]

The Speeton clay beds are quite unconformable with the Hunstanton and chalk beds above them, and are about 500 feet thick. This clay is not uniform either lithologically or palæontologically, but exhibits at least 7 subdivisions, each distinguished by a well-marked fauna.

The three upper divisions belong to the Neocomian system, the four lower to the Jurassic, viz., the Portlandian, Upper Kimmeridge, Middle Kimmeridge, and Lower Kimmeridge.[3]

[1] "The Hunstanton Red Chalk (base of Upper Cretaceous) rests in succession on Upper Neocomian (Aptien) at Speeton, on Lower Neocomian at West Heslerton, on Portlandian at Knapton, on Kimmeridge Clay at North Grimston, on Corrallian Oolite at Leavening, and on Inferior Oolite at South Grimston."—Judd, Q. J. Geol. Soc., vol. xxvi., p. 330–1.

[2] Marked on the 6-inch Ordnance Map as Black Cliff, Middle Cliff, and New Closes Cliff.

[3] See Prof. Judd "On the Speeton Clay" (Q. Jour. Geol. Soc., vol. xxiv.), where the subject is exhaustively treated.

A.—Upper Neocomian.—The highest beds are black clays with few or no organic remains—*Belemnites semicanaliculatus, B. minimus, Vermicularia Phillipsii*, and *Rhynchonella sulcata*, &c.; dark-blue clays occur below.

The base of the Upper Neocomian is formed by the "Cement bed," which consists of light-blue tenacious clay, containing layers of pale or nearly white septaria, composed of argillaceous Limestone.[1]

Fauna.—This Cement-bed, with the other portions of the Upper Neocomian beds, contains a rich fauna. No less than 55 genera and 94 species have been found in it. The characteristic species are *Perna Mulleti, Exogyra sinuata, Pecten elongatus, P. orbicularis, Am. Deshayesii, Belemnites semicanaliculatus, Ancyloceras? grandis, Thetis Sowerbyi, Panopæa plicata, P. neocomiensis, Alaria, Vermicularia Sowerbyi, Terebratula sella*, &c. These black and dark-grey Clays and Cement-beds measure about 150 feet.

Correlation with Southern Beds.—The general agreement of these species with those of the Lower Greensand of the south is at once apparent, especially amongst those which are most characteristic and have the widest geographical range. The difference of the conditions under which the two series were deposited, and the distance separating the respective localities, is sufficient to account for the differences between their fossil contents. It is to the Atherfield Clay of the Isle of Wight that we must look for the closest analogies with the fossils of the Yorkshire Upper Neocomian strata.

This highest division of the Speeton Clay is not represented in the Hilsthon and Hilsconglomerat of Römer, which appear to be the nearest equivalents of the second and third divisions of the Yorkshire deposit, or the Middle Zone with *Pecten cinctus*, and the Lower with *Ammonites noricus*.

B.—Middle Neocomian.—These beds comprise the second division of the Speeton Clay, and are about 150 feet thick. Immediately below the Cement beds occur about 80 feet of dark-blue clays, containing a few septaria and fossils.

Fauna.—The latter are *Belemnites jaculum, B. semicanaliculatus, Vermicularia Phillipsii, Pecten cinctus* (large), and *Exogyra sinuata* (the large and typical form). Succeeding these are fossiliferous clays, 40 feet thick, characterised by the abundance of the gigantic form of *Pecten cinctus, Exogyra sinuata* (typical form), and *Bel. jaculum*. Layers of brown nodules succeed, and almost every nodule contains the Macrourous crustacean, *Meyeria ornata*,[2] while in larger scattered nodules in the same portion of the bed occur the fine "*Ancyloceras Duvalii*." The base of the Middle Neocomian is distinguished by dark clay, 30 feet thick, comprising regular layers of brown Septaria, which contain *Ancyloceras Duvallii* and *A. Emerici* (the Ancyloceras beds of Judd), and is the metropolis of the distinctive *Belemnites jaculum*.

[1] Both the septaria and the clay of the Cement-bed are of considerable value economically. See Appendix C. to Prof. Judd's Paper, *loc. cit.*, p. 249, for particulars.

[2] This is the "shrimp bed of collectors." *Meyeria Vectensis* is the typical crustacean in the Atherfield section (Isle of Wight).

This Middle Division is the Zone of *Pecten cinctus*, 150 feet thick. Twenty-five genera and 40 species are known, amongst them 8 species of Ammonites, 3 Belemnites, and the Ancyloceri named, with the distinctive *Pecten cinctus*.

The Foreign or Continental equivalents of this division (through palæontological evidence) are the Hilsthon of Hanover and Brunswick. The labours of Römer [1] and von Strombeck [2] show the close relationship between the Middle and Lower Neocomian of Yorkshire with that of Hanover, &c.

C.—Lower Neocomian.—Three well-marked Ammonite Zones characterise this division,—

1. The Zone of Am. Speetonensis,
2. „ „ Noricus,
3. „ „ Astierianus,

occurring in 200 feet of strata.

a.—Zone of Am. Speetonensis.—This uppermost Zone consists of about 100 feet of dark-blue clays. The type Ammonite and *Exogyra subplicata*, which takes the place of *Exogyra sinuata*, are entirely confined to this horizon.

Fauna.—The associated Ammonites are *Am. rotula*, *Am. nisus*, *A. marginatus*, *A. nucleus*, with *Belem. jaculum*, and *Thracia Phillipsii*, *Waldheimia celtica*, *Pholadidea constricta*, &c. At the base of the Zone occur *Ancyloceras puzosianum*, *Anc. Duvalii*, and *Anc. Emerici*.

b.—Zone of Am. Noricus.—Fifty feet of clays. Comparatively few fossils occur in these clays; not more than 15 species have been detected. The same Ancyloceri occur with 4 species of Ammonites, *A. rotula*, *A. marginatus*, and *A. furcillatus*, and the type of the Zone, *A. Noricus*.

c.—Zone of Am. Astierianus.—Pyritic shaly clays, from 50 to 100 feet thick, with marked palæontological features, characterise this Zone. *Am. Astierianus*, and its allies, *Am. hystrix*, *Am. multiplicatus*, and *Belemnites lateralis* (the latter species in thousands), range through the series of Clay beds.

Characteristic Fossils.—The most abundant and characteristic fossil of this bed is *Exogyra subsinuata* or *Ex. Couloni*.[3] *Toxaster complanatus* adds to the correlation with the Continental deposits of the same age (Calcaire Neocomien à *Toxaster complanatus*, d'Archiac). "The presence in the Yorkshire Lower Neocomian of such characteristic Continental species as *Exogyra Couloni*, *Toxaster complanatus*, *Ammonites Astierianus*, *A. Noricus*, *Belemnites lateralis*, and others, leaves little to be desired in establishing this correlation."

[1] Verstein. Nordd. Kreide. 1840–41.

[2] Ueber die Neocomien-Bildung, &c. Zeitschrift d. D. Geol. Gesellsch. vol. i. 1849. The Middle Neocomian of Speeton is the equivalent of the Tealby series of Lincolnshire (Judd.)

[3] This shell is most abundant in, and characteristic of, the Neocomian Limestone of Central and South-Eastern France.

The Fauna of the Lower Neocomian comprises 25 genera and 47 species, 21 of which are Cephalopoda,—

The Zone of	Am.	Speetonensis	37 species.
„	„	Noricus	15 „
„	„	Astierianus	12 „

Between the Zones of *Am. Speetonensis* and *Am. Noricus* 11 species are common; between those of *Speetonensis*, *Noricus*, and *Astierianus* only 3 species; and between *Am. Noricus* and *Am. Astierianus* also there are only 3, thus showing the distinctiveness of the grouping and the value of the Zones.

The fauna of the whole, or all 3 divisions of the Yorkshire or northern type of the Neocomian strata, numbers 54 genera and 138 species, varying through the three zonal divisions as follows:[1]—

The Upper Neocomian	89	species.
The Middle „	41	„
The Lower „	42	„

The Tealby Series, Lincolnshire.[2]

The extensive series of sands, sandstone, grits, limestones, clays, and ironstones seen on the west side of the Lincolnshire Wolds fall into the 3 chief divisions[3] of the Tealby series,—

1. The Upper Ferruginous sands, non-fossiliferous . .	20 ft.	thick.
2. The Tealby series, consisting of alternate beds of sandy clay and limestone, with an interesting suite of fossils	40 to 50	„
3. The Lower Sand and Sandstones, containing few fossils	30 to 40	„
	110	„

The Tealby Series includes a great variety of rocks, the chief or most characteristic being the sandy limestone, "Greystone," with *Pecten cinctus*,[4] *Exogyra sinuata*, *Belemnites semicanaliculatus*, *Ostrea frons*, *Pecten orbicularis*, and *Rhynchonella parvirostris*, which are the most important species. Thirty genera and 46 species comprise this important fauna, which is essentially the same as the Middle Group of Speeton, or the Zone of *Am. cinctus*. Centra and teeth of Ichthyosauria and Plesiosauria—*Crioceras Bowerbanki*, *Ancyloceras Duvalii*, and *A. puzosianus*—are found as at Speeton, with other connecting forms, fully attesting the correlation of the two series.

[1] This is by no means exhaustive. There are many new and undescribed species.

[2] Professor Judd "On the Strata which form the Base of the Lincolnshire Wolds," Q. Jour. Geol. Soc., vol. xxiii.

[3] The village of Tealby and surrounding country exhibit these beds, hence the term, "Tealby" series.

[4] This shell occurs here from 9 to 12 inches in diameter, and always lying on the lowest or convex valve.

The Atherfield Clay.

Isle of Wight.—This formation was so named by Dr. Fitton from the fine section exposed in the cliffs at Atherfield, in the south of the Isle of Wight, between Blackgang Chine and Rocken End, where these beds immediately underlie the Gault, and rest upon the Wealden clay.[1] Dr Fitton determines 55 distinct beds in this section, and places them in 16 groups. The fauna of the whole 55 beds numbered 155 species, many of which range through the whole series, although the strata are 800 feet thick.

The following is a detailed section of the Upper Neocomian beds at Atherfield, Isle of Wight, where, or between this place and Blackgang, the whole series is seen from the Wealden below to the Gault above. The thickness here is 802 feet; at Hythe, near Folkstone, it is only 406 feet:—

		Strata.	Ft.	In.
Upper Beds	49 to 55	Various clays and sands	118	4
	46 to 48	Upper clays and sand rock	118	0
	45	Ferruginous bands of Blackgang above	20	6
	41 to 44	Sands of Walpen, under cliff	97	0
	40	Foliated clay and sand	25	0
	38, 39	Cliff-end sands	19	3
	36, 37	Upper Gryphæa beds	16	0
	35	Walpen and Ladder sands	42	0
	26 to 34	Upper Crioceras group	46	2
	24, 25	Walpen clay and sands	57	0
	17 to 23	Lower Crioceras group	16	3
	14 to 16	Scaphites group	50	4
	11 to 13	Lower Gryphæa beds	32	0
	4 to 10	The "Crackers"	85	0
	3	Atherfield clay	60	0
	1, 2	Perna beds (lowest beds)	5	3

It is important to name some of the characteristic species that range through the Atherfield strata, and as occurring in certain beds.

Atherfield Fauna.—No. 1. *The Lower Perna beds* contain 28 genera and 50 species—none of which had appeared before—no form whatever occurring common to the Jurassic and Cretaceous *Ammonites furcatus*, *Panopæa plicata*, *Pholadomya Martini*, *Perna Mulleti*, *Gervillia alæformis*, *Gryphæa* (*Exogyra*) *sinuata*, *Hinnites Leymeriei*, *Trigonia caudata*, *Terebratula sella*, *T. Gibbsiana*, and *Rostellaria Robinaldina*.[2]

No. 2. *The Upper Perna Bed.*—No. 2 in Fitton's section contains *Ammonites Deshayesii*, *A. inflatus*, *Panopæa neocomiensis*, *Hemicardium Austeni*, *Trigonia Dædalea*, *Corbis* (*Sphæra*) *corrugata*, *Perna Mulleti*, *Hinnites Leymeriei*, and *Holaster complanatus*. Twenty-seven genera and 52 species known.

[1] This great section is exhaustively described by Dr. Fitton in the Q. Jour. Geol. Soc., vol. iii. pp. 289–327, 1847.

[2] *Vide* Fitton, *loc. cit.*, for *every species* occurring through the whole of the 55 beds, which are detailed in tabular form, stratigraphically and palæontologically.

No. 3. *The Atherfield Clay.*—Twenty-three species, illustrating 17 genera, occur in this clay, which gives name to the whole group. The same ammonites are found as in the Perna bed No. 2, associated with *Venus vectensis, Lima Cottaldina, Pinna Robinaldina, Gryphæa sinuata,* and *Holaster complanatus.*

Group III. **The "Crackers."**—Nos. 4 to 10 of Fitton's section. A prominent group containing solid nodules, to which the name of "crackers" was applied. The most remarkable portion of the whole section has a total thickness of 90 feet. All the clays resemble Fuller's Earth. The sands in the *lower* bed are highly indurated, and termed the "Lobster bed," from the occurrence of *Meyeria* (*Astacus*) *vectensis*, or *M. magna.* This "crackers" group is divided into 10 beds or stages, and the *recurrences* of the species in the rich fauna through these 10 number nearly 200 species. *Am. Deshayesii* is the characteristic ammonite through these 10 beds.

Group IV. **The Lower Gryphæa Group.**—Nos. 11, 12, 13.

No. 12. *Terebratula sella bed.*—This distinctive shell occurs in the greatest profusion, with *Perna alæformis. T. sella* more or less pervades the whole section, but nowhere so abundantly as here.

No. 13. *The Lower Gryphæa bed.*—Very conspicuous under Atherfield High Cliff, and about 10 feet thick. Fine examples of the characteristic shells, *Hinnites Leymeriei, Ostrea Leymeriei,* and large *Exogyra sinuata,* with the *T. sella,* distinguish this bed. Eighteen genera and 25 species occur.

Group V. **Scaphites Group** (14, 15, 16).

No. 14. Brown, sandy, concretionary series. Each concretionary mass frequently encloses or contains a single *Scaphite* or *Ammonite* as a nucleus. *Exogyra* (*Gryphæa*) *sinuata* in agglutinated masses and *Gryphæa Couloni* abound, with *Lima semisulcata* and *Pecten orbicularis.*

No. 15. The Scaphite nodules are from 18 inches to 2 feet in thickness. *Ammo. Deshayesii* of great size occur here. *Scaphites gigas, S Hillsii,* and *Nautilis radiatus* distinguish this zone.

No. 16. The space (22 feet) between No. 15 and the lowest Crioceras range is occupied by dark-grey sandy clay, containing *Exogyra sinuata, Pinna Robinaldina,* and *Terebratula sella.*

Groups VI. and VIII. **Crioceras Ranges.**

Nos. 17 to 33. The 2 groups in which the genus *Ancyloceras* of D'Orbigny has hitherto occurred are separated by a thickness of about 50 feet. The fossils of the beds 17 to 23 (Crioceras range) number 16 genera and 18 species. Amongst them are *Ammo. Martini, Crioceras Bowerbankii* (*Ancyloceras,* D'Orb.), *Scaphites gigas, Gervillia anceps,* and *Gryphæa* (*Exogyra*) *sinuata.*

Group VII. **Walpen and Ladder Sands and Clay** (Nos. 24 and 25).

No. 24. The *Crioceras nodules* (23) are succeeded by (24) a dark-greenish mud, composed of sand and clay, about 27 feet thick. *Am. Martini* is the chief species, with *Panopæa elongata* and *Gryphæa,* sp.

No. 25. This clay bed has been the chief agent in the production

of the Atherfield undercliff. *Panopæa mandibula*, *Pinna Robinaldina*, and *Corbula striatula* are the chief forms.

Group VIII. **Upper or Second Crioceras Ranges.**—Nos. 26–34.

Group IX. **Walpen and Ladder Sand.**—No. 35.

Group X. **The Upper or Cliff-End Gryphæa Group.**—Nos. 36 and 37. *Rostellaria Robinaldina*, *Thetis minor*, *Gervillia Forbesiana*, and *Lonchopteris Mantellii* are the chief fossils.

Group XI. **Cliff-End Sand with Concretions.**—Nos. 38 and 39.

No. 38. Uniform sand, 14 feet thick, with a thin retentive fossiliferous clay at the bottom, with *Trigonia dædalea*, *Ammo. Martini*, and *Pinna Robinaldina*.

Group XII. **Foliated Clay and Sand.**—No. 40.

Group XIII. **Sands of Walpen and Black-Gang Undercliff.**—Nos. 41–44.

Group XIV. **Ferruginous Bands of Black-Gang Chine.**—No. 45 (*a. b. c.*)

This group is one of the most remarkable in the whole section. Its species can be identified with those of Perna group at *the base* of the section; they are also the same as those found at Parham Park and other places in Sussex, and near Sandgate in Kent.

A large fauna occurs in this subdivision—41 genera and 48 species—closing the fossiliferous portion of the Atherfield section.[1]

Atherfield Clay in Kent and Sussex.

Kent.—This is first seen at the lowest tides, opposite Shorncliffe Battery—rising from thence towards the west, it ranges along the line of inland cliff to Aldington Knowl. Strong springs mark its line of junction with the "Hythe Beds or Kentish Rag." Its thickness is not known.

Sevenoaks' Tunnel is in part driven through the Atherfield Clay. *Exogyra sinuata*, *Perna*, *Ostrea*, &c., occur in the concretionary masses. At the northern entrance to the tunnel the Atherfield Clay is faulted against the Hythe beds (Kentish Rag). At Red Hill it occurs in the railway-cutting, and contains the following fossils:[2]—*Arca Raulini*, *Panopæa depressa*, *Perna Mulleti*, *P. alæformis*, *Gervillia aviculoides*, *Pecten obliquus*, *Pinna sulcifera*, *Gryphæa* (*Exogyra*) *sinuata*, *Nautilus radiatus*, and *Trigonia dædalea*, &c. At East Shalford a well-defined fauna also occurs;[3] at Haslemere the beds are disturbed, and dip at high angles, showing the whole of the Atherfield Clay as exposed in the middle of the railway-cutting.

Sussex.—Little is known of the Atherfield Clay in Sussex; it continues at the base of the Hythe beds along the strike of the Kentish Rag (Topley, *loc. cit.*, pp. 112–116).

[1] For lengthened explanation, see Fitton, *loc. cit.*, pp. 307–8. See also the elaborate Table of Distribution of Fossils, with the Coast Section, where all the above-named localities are shown also, with the numbers quoted above.

[2] *Vide* Dr. Fitton. Proc. Geol. Soc., vol. iv. p. 101.

[3] Godwin-Austen. Q. Jour. Geol. Soc., vol. iv.

Hythe Beds (The Kentish Rag beds of Fitton).—The thickness of the Hythe or Kentish Rag beds is about 60 feet. In places they are highly fossiliferous, especially so at Hythe and Lympne (west of Hythe),[1] again in the northern part of the county, in the famous quarries at Maidstone, also at Sevenoaks; the beds are fully developed and fossiliferous. About Maidstone, as elsewhere, the Hythe beds are "Kentish Rag" with "Hassock" between the courses or layers of stone.

The so-called "Iguanodon Quarry" at Maidstone exhibits the greater part of the Hythe beds, with *Trigonia caudata*, *Exogyra sinuata*, *Gervillia aviculoides*, coniferous wood, and *Pinnites Mantellii*, *P. patens*, and *P. Benstedi*. In the Isle of Wight the Hythe and Sandgate beds are best observed in the coast section between Dunnose Point and *the middle* of Sandown Bay. The railway-cutting north of the tunnel at Sevenoaks exposes a fine section of the Hythe beds, with the underlying Atherfield Clay faulted against them.[2]

The Hythe beds are about 200 feet thick at Leith Hill, and probably 240 or 250 at or around Godalming and Guildford. They attain their greatest known thickness in the Hindhead district, where at the Devil's Punch-Bowl they cannot be less than 300 feet. The entire flora and fauna of the Hythe beds comprise 156 species, illustrating 82 genera.

Sandgate Beds.—The Hythe beds in the vicinity of Folkestone are succeeded by dark-coloured argillaceous sand, geologically known as the "Sandgate beds," and representing the middle or argillaceous division of Fitton. In East Kent the general composition of the Sandgate beds is dark argillaceous sand and clay, the dark colour being chiefly due to green particles of glauconite (a hydrous silicate of iron and alumina). The Sandgate beds are about 80 feet thick.[3] The junction with the Hythe series beneath often exhibits characters closely resembling those of the junction of the Gault and Folkstone beds, viz., phosphatic nodules and pebbles, with fossils in fragments or casts, and bored wood (*Lithodomi*). This phosphate bed at Great Chart has yielded, amongst other remains, *Cytherea parva*, *Panopæa plicata*, *Pecten quinquecostatus*, *Rhynchonella Gibbsiana*, *R. sulcata*, *Terebratula oblonga*, *T. sella*, *Trigonia alæformis*, *T. ornata*, and coniferous wood.

"Fuller's Earth" accompanies the Sandgate beds in many localities, and the typical area for this deposit is at Nutfield, near Reigate in Surrey, where it is on the same geological horizon as at Maidstone. It is also probably upon the same horizon as the Bargate Stone of God-

[1] The large collection of Kentish Rag fossils from Lympne, once belonging to Mr. Hills of Court-at-Street, is now in the Museum of Practical Geology in Jermyn Street. See Dr. Fitton, for sections, &c., west of Sevenoaks. Trans. Geol. Soc., ser. 2, vol. iv. pp. 133.

[2] See Mr. Topley: Mem. Geol. Survey, "Geol. of the Weald," Hythe beds, pp. 116–127.

[3] The beds exposed at lowest tides on the east side of Folkestone Harbour are probably Sandgate beds—below the "Folkestone beds."

alming. At Nutfield the Fuller's Earth encloses masses of crystallised sulphate of barytes, transparent, and chiefly of a topaz colour.[1]

The Sandgate beds are well seen in the neighbourhood of Pulborough, and at Codmoor Hills. The fossiliferous nodules contain *Rhynchonella Gibbsiana*, *Cyprina angulata*, *Thetis Sowerbyi*, and *Trigonia alæformis*.

The fauna of the Sandgate beds is poor in species, and only 6 classes appear to be represented, viz., the Protozoa, the Brachiopoda, Lamellibranchiata, Gasteropoda, Cephalopoda (*Ammo. Deshayesii*, *Nautilus radiatus*), and *Ichthyosaurus campylodon*.

Folkestone Beds.—This group of rocks at Folkestone rests upon the Sandgate beds, and occurs in the cliffs both on the east and west sides of Folkestone. They constitute the ferruginous or upper division of Fitton, and are composed of light-coloured sands, sometimes very coarse, with layers of siliceous limestone (Folkestone stone) and chert. This division has been minutely described by Dr. Fitton.[2] The thickness is about 50 feet, in places greater.

These beds rise gradually in the cliff to the west of Folkestone, exposing the Sandgate beds below. Most of the base of the cliff between Folkestone and Sandgate is occupied by the Sandgate beds.

Fauna.—The Folkestone series is comparatively unfossiliferous, and the fossils occurring near the top or junction with the Gault are mostly in fragments. The higher beds near Copt Point yielded *Arca Raulinana*, *Lima parallela*, *Lucina arduanensis*, *Ostrea frons*, *Panopæa plicata*, *Pecten interstriatus*, *Terebratula sella*, *Thetis Sowerbyi*, *Exogyra sinuata*, and *Holaster* sp.

The phosphatic bed lies at the summit or junction with the Gault clay. Nodules frequently occur, either loose in the sands, or in hard concretionary masses on the blocks of stone. Associated with these nodules and phosphates have been obtained *Ammonites Beaudantii*, *Am. mammillaris*, *Exogyra conica*, *Inoceramus Salamoni*, *Natica Gaultina*, *Nucula pectinata*, *Pecten orbicularis*, *P. quinquecostatus*, and *Rostellaria*.

The lowest portion of the Folkestone beds, east of the harbour at low-water spring-tides, yields the following species:—*Am. Deshayesii*, *Corbula elegans*, *Gervilla anceps*, *Lucina Duriniana*, *Panopæa plicata*, *Rhynchonella depressa*, *R. sulcata*, *Thetis Sowerbyi*, and *Ichthyosaurus campylodon*.[3]

The entire fauna of the Folkestone beds numbers only 24 species, omitting the junction bed, which contains 10. They are spines of *Holaster* sp., *Rhynchonella sulcata*, *Exogyra conica*, *Inoceramus* sp., *Modiola parallela*, *Ostrea frons*, *Pecten striato-punctata*, *Arca Raulini*, *Gastrochæna pyriformis*, *Panopæa plicata*, *Ammonites Beaudantii*, and *A. interruptus*.

Range.—The range of the Folkestone beds has continued as far westward as Lyme Regis; they are the oldest Cretaceous deposits in that area. The structure, composition, and succession of the strata at Black Ven are more in unison with those of the Folkestone beds than

[1] For many localities and particulars relative to this deposit, see Mr. Topley, *loc. cit.*, p. 131–33.

[2] See Dr. Fitton: "Strata below the Chalk," Trans. Geol. Soc., 2d series, vol. iv. pp. 105–108.

[3] This bed probably belongs to the Sandgate series, or near the junction of the two groups. *Vide* pp. 139–43 of Mr. Topley's memoir (*loc. cit.*) for the distribution and sections, &c., of the Folkestone beds.

with the Gault or Upper Greensand; at the period of the deposition of the Folkestone beds their area was greatly increased to the north-west and north. The Upper Neocomian series of Devizes, Calne, and Seend in Wiltshire, of Farringdon in Berkshire, and the Carstone beds of Norfolk, all clearly belong to the Folkestone series; the ferruginous or upper division of Fitton. On the same area, or near Lyme Regis, the Gault is probably represented by the yellowish-brown or foxy sand, which is from 70 to 80 feet thick, and is interposed between the true Upper Greensand and the Cow-stone beds of the Black Ven section, between Lyme and Charmouth.

Comparison with the Neocomian Beds of Northern Europe.[1]

Heligoland.—Intermediate between North Germany and Speeton, the upper part of the Middle Neocomian strata, or the *Speetonensis* beds, are exhibited on the Island of Heligoland in the German Ocean. According to F. Ad. Römer (Verst. Nordd. Kreidegeb., 1841) and Wiebel (Die Insel Helgoland, Hamb., 1848), the fauna of the Heligoland *Speetonensis* beds is precisely that of Yorkshire. Twelve of the 14 species are the same. Vestiges of the Hunstanton Red rocks also occur at Heligoland.[2]

Holland.—Although drift-covered, beds of this age occur with *Perna Mulletii* and *Crioceras Duvallii* at the village of Lösser, near Oldensaal. F. Römer has described the beds and fossils. Yellow iron-shot sandstone, similar to that of the Teutoburger Wald and Tealby, enables us to refer the fossils without doubt to the Middle Neocomian.

Westphalia.—The first exposure of the Neocomian of North-west Germany is in the *hils-group* of Bentheim, where the beds resemble the Tealby series, and the species are referable to the Middle Neocomian.

Fauna.—They contain *Crioceras Duvalii, Belemnites lateralis, Panopæa neocomiensis, Pecten cinctus, P. orbicularis, Exogyra sinuata, Avicula Corneuliana,* and *Thracia Phillipsii.*

From Bentheim eastwards, south of this at Ahaus, black plastic clays occur, containing Upper Neocomian species, amongst them *Ammonites Deshayesii, A. Martini, Ancyloceras gigas, Panopæa neocomiensis, Pinna Robinaldina, Holaster lævis,* all British Upper Neocomian species.

Along the Teutoburger Wald, from Ibbenbuhren to Bielefeld, the beds everywhere contain in abundance the large *Pecten cinctus.* A

[1] Consult Professor Judd's able paper for correlation and distribution, Q. J. G. S., vol. xxvi. pp. 333–347.

[2] Heligoland is 325 miles due east of Speeton, and 150 miles from the nearest exposure of the Neocomian beds of the Continent (Judd, *loc. cit.*) Possibly the geographical extent or distribution of the Neocomian strata was equal to that of the Wealden through Germany and Northern France.

large fauna occurs in the sandstone of the Teutoburger Wald.[1] They lie upon the same horizon as the Tealby limestones and the middle portion of the Speeton Clay, or the *Zone of Am. Noricus*.

Fauna of the Noricus Beds.—The characteristic species are—*Nautilus pseudo-elegans, Belemnites lateralis, Am. Noricus, Am. Gervilianus, Am. bidichotomus, Ancyloceras Duvalii, A. Emmerici* and *A. grande, Pecten cinctus* (abundant), *Perna Mulleti, Avicula Corneuiliana, Trigonia rudis, Thetis Sowerbyi, Pholadomya gigantea, Waldheimia celtica, Holaster lævis*, and *Toxaster complanatus*. These, and many more species in the Teutoburger beds, are British forms. (For complete list, see Prof. Judd, *loc. cit.*)

Hanover.—These strata have been fully described by F. Ad. Römer under the titles of "Hilsthon" and "Hilsconglomerat." "They are chiefly seen on the flanks of the hill-chains of the country (which are exposed above great plains covered with drift), as the Deister, the Lindener Berg, the Osterwald, the Suntel, and especially the Hils" near Hildesheim, from which the beds take their name.

Hanoverian Fauna.—Throughout Hanover thick beds of blue clay represent the Neocomian (Hilsthon). The *upper part* of these clays contains a well-defined Aptian or Upper Neocomian fauna, including *Ammonites Deshayesii, Am. Martini, Am. Nisus*, while the *Lower portion* contains an unmistakably Middle Neocomian fauna, allied to our own, and comprising *Pecten cinctus* (abundant and large), *Ammonites clypeiformis, Thracia Phillipsii, Meyeria ornata*, &c.

At Bredenbeck, W. of Hanover, and along the northern foot of the Deister, the lower beds of the Hilsthon are well exposed, and contain a large Lower Neocomian fauna, comprising 16 genera and 27 species, 9 of which are ammonites, amongst them *Am. Noricus, Am. concinnus, Am. marginatus, Am. Gervilianus*, and *Ancyloceras Emmerici, Pecten cinctus, Pholadidea constricta*, and *Pleuromya solenoides*.

Elligser Brinke Fauna.—In the chain of the "Hils," the Neocomian clays are well developed, especially so at Elligser Brinke near Delligsen. They contain a large series of fossils from the Lower part of the Middle Neocomian, including 28 genera and 42 species. The characteristic forms are *Belemnites lateralis, B. jaculum, Nautilus radiatus, Ammonites noricus, Am. clypeiformis, Pleurotomaria gigantea, Exogyra sinuata, E. haliotoidea, Avicula Corneuiliana, Terebratula faba, T. tamarindus*, and *T. sella, Rhynchonella varians*, and *Waldheimia celtica*. No less than 20 of the 42 known species occur in Britain.

Dr. Brauns has described sections and fossils found in the railway between Kreiensen and Holzminden along the S.-W. foot of the Hils chain.[2]

The Harz.—Prof. Beyrich has shown that along the northern foot of the Harz range, between Harzburg and Goslar, there occur Neocomian beds,[3] referred by Mr. Judd to the Middle Neocomian group, the beds resembling the Tealby series. He collected *Pecten cinctus, P. orbicularis, Exogyra sinuata, Belemnites jaculum, B. lateralis, Ostrea macroptera, Serpula antiquata*, and *S. filiformis*, all British species.

[1] *Vide* F. Römer, Leonh. und Bronns. Jahrb., 1845, p. 267; 1850, p. 385; 1852, p. 185. Also Zeitschr. d. Deutsch. Geol. Gesell. vi., 1854.

[2] "Die Stratigraphie und Paläontographie des Sudöstlichen Theiles der Hilsmulde." Palæontographica, xiii. p. 65, 1865.

[3] Beyrich, Zeitschr. d. deutschen Geol. Gesellsch. i. p. 302, Karte iii., Karte xv.; ix. p. 415; xi. p. 73, &c.

Brunswick.—Nowhere else in N.-W. Germany is the Neocomian series so complete. The labours of M. von Strombeck, through his memoirs and maps, have made us acquainted with the geology and palæontology of the entire district,[1] enabling us fully to correlate all the N.-W. German and Neocomian series with those exposed in Yorkshire and Lincolnshire, and intermediate areas. All three divisions of the Neocomian strata are present or represented in Brunswick.

The Upper Neocomian exhibits the following succession and associated fauna:—

1. Whitish marly clay seen near Brunswick, and at several other points. "Gargas-Mergel" (Zone of "*Ammonites nisus*," von Strombeck).
   The chief species are *Ammo. nisus, Am. Deshayesii, Am. Martini, Toxoceras Royerianus,* and *Rhynchonella lineolata.*
2. Dark-coloured clays with *Ammonites Martini, Am. Deshayesii, Crioceras,* &c. Zone of "*Am. Martini*" (von Strombeck).
3. Dark-blue clays, with septaria and few or no fossils.

The Middle Neocomian is represented in Brunswick by

4. Dark-blue tenacious clay full of fossils ("Speeton Thon.")
   Zone of "*Belemnites brunswicensis*" of von Strombeck, with a fauna of 12 species, 9 of which are those of Speeton Cliff. The chief forms are *Pecten cinctus, Avicula Corneuiliana, Ammo. nisus, Panopœa plicata, P. neocomiensis,* and *Meyeria ornata.*
5. Dark-blue clays abounding with Ancyloceras.
   Zone of *Ancyloceras* (*Crioceras*) *Emmerici*, von Strombeck). Few species occur.
6. Unfossiliferous clays.
7. Beds of clay full of *Exogyra sinuata.*
   (Zone of "*Ostrea Couloni* var. *Aquila*," von Strombeck.)
8. Unfossiliferous clays.
   The total thickness of these clays, representing the Upper and Middle Neocomian, von Strombeck states to be in places upwards of 400 feet.

The Lower Neocomian.—Beds of Limestone and sandy marl, with nodules of iron ore, characterise the Lower Neocomian series. The characteristic *Toxaster complanatus* occurs in the uppermost beds. The whole series, which does not exceed 50 feet in thickness, is crowded with fossils. The Echinoidea predominate, no fewer than 10 species being present in these beds, which also occur in the Marnes d'Haute-rive, &c. (Lower Neocomian) of the Jura. Thirty genera and 54 species are recorded by von Strombeck as occurring in this Lower division.

Characteristic Fauna.—The characteristic forms are—

Ammonites Astierianus, Am. noricus, Belemnites lateralis, Ostrea macroptera, Exogyra couloni, Pecten cinctus, Serpula gordialis, S. antiquata, Terebratula sella, T. faba, and *T. tamarindus.* The 10 species of Echinoidea referred to above are *Toxaster complanatus, Holaster Hardyi, Dysaster ovulum, Pygurus Montmoulini, Nucleolites* (*Echinobrissus*) *Olfersii, N. Gresslyi, Pyrina pygœa, Holectypus macropygus, Diadema* (*Pseudodiadema*) *rotulare,* and *D. Bourgueti.*

For the remaining 32 species see Prof. Judd, Q. Jour. Geol. Soc., vol. xxvi., pp. 344–5.

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[1] Geognostische Karte des Herzogthums Braunschweig, 1856. Ueber die Neocomian-Bildung. &c. Zeitschr. d. d. Geol. Gesell., vol. i., p. 462. Bemerkungen über den Hils-konglomerat und den Speeton-clay bei Braunschweig. Neu. Jahrb., 1855.

TABLE LXXXVII.—*Comparative Table of the Neocomian Strata of Northern Europe. By Prof. J. W. Judd, F.R.S.*

Yorkshire.		Lincolnshire.	Heligoland.	Westphalia.	Hanover.	The Harz.	Brunswick.
Gault. Albien (D'Orb.)	Hunstanton Red Rock. .	Hunstanton Red Rock.	Hunstanton Red Rock.	Red sandstones with various Gault Clays, including the "Flammenmergel."	Gault Clays, including the "Flammenmergel" and sands of the Lower Quader.	Gault Clays, including the "Flammenmergel" and sands of the Lower Quader.	Gault Clays, including the "Flammenmergel."
UNCONFORMITY.						UNCONFORMITY.	
Upper Neocomian. (Aptien) D'Orb. Rhodanien and Aptien (Renev.)	Black clays Dark-blue clays. . Ft. 120 "Cement beds" . . 30	Upper sands.	Absent.	Upper Ironshot Sandstones of Ochtrup, &c. Clays of Ahaus.	Hilssandstein. Upper part of Hilsthon.	Subhercynischer Unter-Quader. Clays of Olhey, &c.	Whitish marly clays (Gargas Mergel), von Strombeck. Dark-coloured clays (*Zone of Am. Martini*, von Strombeck). Dark-blue unfossiliferous clays.
Middle Neocomian. (Urgonien, D'Orb. Barrémien and Urgonien, Coq.)	Dark-blue clays with few fossils 80 (*Zone of Pecten cinctus*). Blue clay with fossils 40 (Ancyloceras beds). Clays with septaria . 30	Tealby Series Clays. Limestones and oolitic ironstones with many fossils.	Absent.	Dark clays with *Bel. jaculum*. Calcareous Ironshot Sandstone of Bentheim, and the Teutoberger Wald with clays and oolitic ironstones.	Lower part of the "Hilsthon." Oolitic Ironstones of Steinlahde, the Osterwald, the Hils, &c. "Hilsconglomerat" (part).	Clays, Limestones, Sands, and Oolitic Ironstones of the north foot of the Harz.	Dark-blue tenaceous clay (Speetonthon, von Strombeck). Dark-blue clays (*one of Crioceras Emmerici*, von Strombeck). Unfossiliferous clays. Beds of clay with *Exogyra sinuata* (*Zone of Ost. Couloni* var. *aquila*, von Strombeck).
Lower Neocomian. (Neocomien, D'Orb. Valanginien and Neocomien, Desor).	Blue clays . 100 (*Zone of Am. Speetonensis*). Blue clays . 50 (*Zone of Am. Noricus*). Blue pyritic clays . . 50 (*Zone of Am. Astierianus*).	Lower sandstones and sands.	Töck Black Bituminous Clays. (*Zone of Am. Speetonensis*). Absent.	Fresh-water Strata. The North-German Wealden.	Elligser Brinke Schist.		Unfossiliferous clays. Limestones and sandy marls full of fossils. "Hilsconglomerat," in part.
Tithonian, Oppel.	UNCONFORMITY.						UNCONFORMITY?
Jurassic.	Portland clays, &c.	Kimmeridge Clay.	Oxfordian.	Weisse Jura = Portlandian and Kimmeridgian.			

PLATE XXV.

CRETACEOUS FOSSILS.

(*Neocomian.*)

1. *Exogyra sinuata* (Sow.) Upper Neocomian. Kent, Sussex, Speeton, &c.
2. *Perna mulleti* (Desh.) Upper Neocomian. Kent, Isle of Wight, &c.

2a. *Do.* Hinge-line showing vertical dentition.

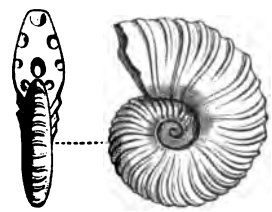
3. *Pecten cinctus* (Sow.) Middle Neocomian. Lincolnshire.
4. *Crioceras* (*Ancyloceras*) *Duvallii* (Léveillé). Upper Neocomian. Speeton, Yorkshire.
5. *Ancyloceras gigas* (Sow.) Upper Neocomian. Isle of Wight, Sandgate, &c.
6. *Nautilus plicatus* (Fitton). Upper Neocomian. Kent, Isle of Wight, &c.
7. *Ammonites* (*Hoplites*) *noricus*. Lower Neocomian. Speeton.
8. *Ammonites Deshayesii* (Leym.) Upper Neocomian. Isle of Wight, &c.

PLATE XXV.

CRETACEOUS FOSSILS.

(*Neocomian*).

1



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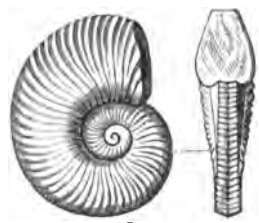

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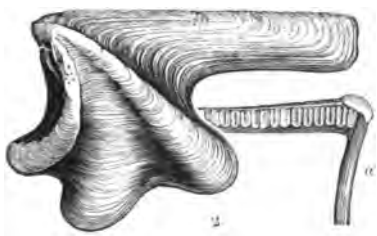

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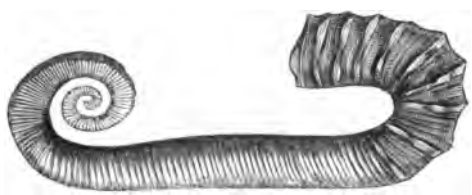

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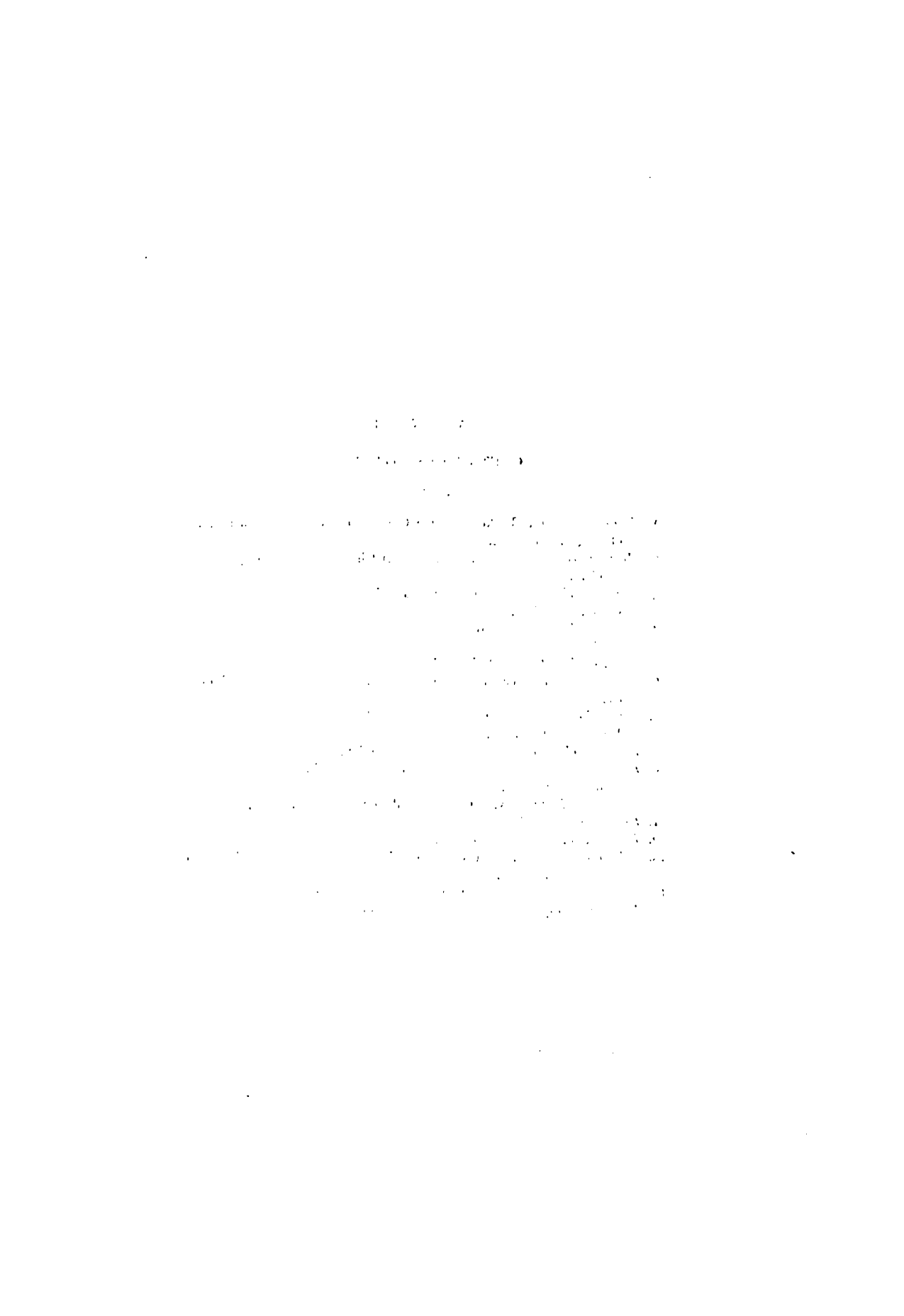


PLATE XXVI.

CRETACEOUS FOSSILS.

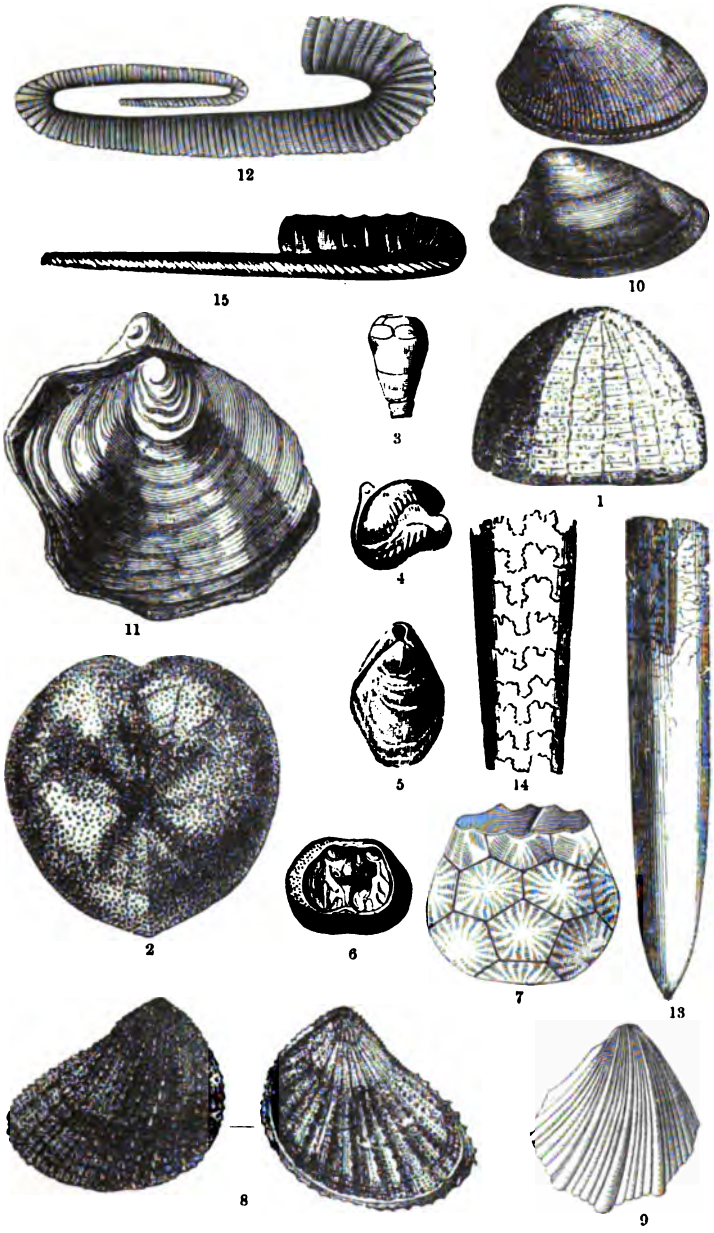
(*Various.*)

1. *Ananchytes ovatus* (Leske). Upper Chalk. Kent, Sussex, Surrey, Isle of Wight, Wilts, &c.
2. *Micraster cor-anguinum* (Leske). Upper Chalk. Kent, Surrey, Sussex, Norfolk, Wilts, &c.
3. *Bourgueticrinus ellipticus* (Miller). Portion of stem and calyx. Upper Chalk. Norfolk, Kent.
4. *Rhynchonella octoplicata* (Sow.) Upper Chalk. Norfolk, Kent, Sussex, Wilts.
5. *Terebratulina striata* (Wahl.) Upper Chalk.
6. *Crania parisiensis* (Defr.) Upper Chalk. Kent, Norfolk, Brighton, &c.
7. *Marsupites ornatus* (Miller). Upper Chalk. Lewes, Basingstoke, Blandford, Brighton.
8. *Plicatula placunea* (Lam.) Upper Neocomian.
9. *Pecten* (*Janira*) *quinquecostatus* (Sow.) Lower Chalk, Upper Greensand, Gault, Neocomian.
10. *Nucula pectinata* (Sow.) Gault. Folkstone, Cambridge, &c.
11. *Exogyra sinuata* (Sow.) Neocomian. Kent, Sussex.
12. *Hamites*, sp. Gault. Folkstone.
13. *Belemnitella mucronata* (Schloth.) Upper Chalk. Norfolk, Kent, Sussex, Cambridge.
14. *Baculites Faujasii* (Sow.) Upper Chalk. Norwich, Sussex, &c.
15. *Ptychoceras adpressum* (Sow.) Gault. Folkstone.

PLATE XXVI.

CRETACEOUS FOSSILS.

(*Various*).



'position distinguishes the Gault, except a general tendency to glauconite grains in its more sandy portions. It produces a good brick-earth, fit for white bricks. Near Folkestone it contains in the lower part a remarkable layer of small, irregular ironstone and phosphatic nodular concretions, which are formed round or contain an ammonite. The ammonite occurring in these phosphatic nodules is *Am. mammillaris*. They are found under the same condition on the north or opposite coast of France.

Geographical Range.—At the commencement of the Upper Cretaceous Epoch, the Gault sea occupied a wide area, extending in England from Folkestone in Kent in the south-east; skirting the line of what is now the Chalk escarpment through the counties of Surrey, Sussex, Hampshire, the Isle of Wight, and parts of Dorsetshire; then taking a northerly or north-easterly direction through the counties of Wiltshire, Berkshire, Oxfordshire, Bedfordshire, Cambridgeshire, and Norfolk, crossing the Wash in Lincolnshire and the East Riding of Yorkshire to Flamborough Head and Speeton; and occupying the whole of the rest of the site where the Eastern Counties of England and the North Sea now are, into Westphalia and Belgium; thence stretching round the axis of Artois to the north of France (Brittany and Normandy) back towards Dorsetshire.

The best sections of the Gault to be seen in England, are at Folkestone, Warminster, Devizes, Cambridge, &c.; in France, in the Departments of Aube, Ardennes, Yonne, &c., and at Wissant in the Pas-de-Calais. It is met with in deep well-sections in Middlesex. The base of the Gault was reached at 1000 feet from the surface in the deep well at Meux's Brewery in Tottenham-Court Road, where it was 160 feet thick, and at Kentish-town 130 feet.

Conditions of Deposition.—From physical as well as from biological evidence, it is clear that the Gault was deposited in a sinking area, the sea being highly charged with sedimentary matter.

The beds of the Lower Gault were a near-shore deposit, gradually becoming deeper, and in time, as the sea-bed sank, the sea also deepened, so as to exterminate the littoral and laminarian forms of life, as shown by the incoming of new genera, which denote deeper sea conditions.

From the same evidence it may be inferred that the Upper Gault sea must have been of long duration, and that it extended, as before stated, all over the area occupied by the Southern and Eastern Counties of England, and over what is now the south-east portion of the British or English Channel, stretching across to the Bas-Boulonnais and the Paris basin.

Gault of Southern England.

Folkestone.—Nowhere in Britain is the Gault so typically and finely shown as in East-Wear Bay, near Folkestone,[1] and nowhere are the

[1] *Vide* "Description of the Gault of Folkestone," by Mr. F. G. H. Price, F.G.S., Q. Jour. Geol. Soc., vol. xxx. pp. 342–368; and by the same writer, "The Gault," being a lecture delivered at the Woodwardian Museum, Cambridge, 1879. Consult also paper by Mr. De Rance, Geol. Mag., vol. v., 1868, pp. 163–171.

TABLE LXXXVIII.—*Showing Particulars of the Gault of Folkestone.*

		Nature of Bed.	Thickness. Ft.	In.	Zones.	Characteristic Fossils.
Upper Gault.	XI.	Pale, cold grey marl, with seam of Greensand, 3 feet 3 inches thick, running through it.	56	3	*Ammonites rostratus.*	*Inoceramus Crispii, Pecten Raulinianus, Ammo. Goodhalli, A. rostratus, A. varians.*
	X.	Hard marl of a pale grey colour.	5	1	*Kingœna lima.*	*Cidaris gaultina, Hemiaster minimus, Kingena lima, Terebratula biplicata, Pentacrinus Fittoni, Plicatula pectinoides, Ammonites rostratus.*
	IX.	Pale-grey marly clay.	9	4½	*Ammonites varicosus.*	*Inoceramus sulcatus, I. subsulcatus, Ammo. varicosus, A. rostratus.*
Passage.	VIII.	Clay darker than above, containing two lines of nodules and remanié fossils.	0	9½	*Ammonites cristatus.*	*Pholas sanctæ-crucis, Mytilus galliennei, Cucullea glabra, Cyprina quadrata, Ammonites Beaudanti, A. cristatus.*
Lower Gault.	VII.	Dark clay, highly fossiliferous.	6	2	*Ammonites auritus.*	*Nucula bivirgata, N. ornatissima, Aporrhais Parkinsoni, Fusus indecisus, Pterocera bicarinata.*
	VI.	Mottled with lightish marking on dark clay.	1	0	*Ammonites denarius.*	*Necrocarcinus Bechei. Turrilites Hugardianus, Ammonites cornutus, A. denarius.*
	V.	Spotted with light markings on darkish ground.	1	6	*Ammonites lautus.*	*Smilotrochus elongatus, S. insignis, Solarium moniliferum, Phasianella ervyna, Ammonites lautus.*
	IV.	Slightly lighter than the above, not mottled.	0	4	*Ammo. Delaruei.*	*Natica obliqua, Dentalium decussatum, Fusus gaultinus, Ammo. Delaruei, Avellana pulchella.*
	III.	Light fawn-coloured clay.	4	6	*Crustaceans.*	*Palæocorystes Stokesii, P. Broderipii, Pinna tetragona, Hamites attenuatus.*
	II.	Very dark clay.	4	3	*Ammonites auritus.*	*Pollicipes rigidus, Pertunculus, Lucina tenera, Corbula gaultina, Arca nana, Nucula pectinata, Cerithium trimonile, Fusus Itierianus, Aporrhais calcarata, Ammo. auritus.*
	I.	Dark clay, dark Greensand, and iron nodules.	10	1	*Ammo. interruptus.*	*Ammonites interruptus, Crioceras astierianum, Hamites rotundus.*
			99	4		*Characteristic Upper Neocomian fossils.*
		Upper Neocomian Folkestone beds.			*Am. mammillaris.*	

beds so fossiliferous. As in the Lias, they may be readily subdivided into Zoological Groups or Zones, the Ammonites being again selected as exponents of the successive life-history of the Gault. At Copt Point, east of Folkestone, the Gault is 100 feet thick, and is divided into Upper and Lower Gault, or "*Lower* and *Upper* Albien," a bed of nodules containing *Ammo. cristatus* being the dividing line between the two groups. The Gault is separated from the Upper Neocomian (Folkestone beds) by a layer of phosphatic nodules, containing *Am. mammillaris* and *A. interruptus;* the thin band below, also containing *mammillaris*, is a well-defined horizon. The two divisions are again subdivided into 11 Zones, each characterised by its special Ammonite. These are here numbered from I. to XI.

Upward Succession of the Ammonite Zones of the Folkestone Gault.

Lower Gault.	1.	The Zone of *Am. interruptus*,	with	49	species.
	2.	„ „ *auritus*	„	72	„
	3.	„ *Crustacea*	„	37	„
	4.	„ *Am. Delaruei*	„	32	„
	5.	„ „ *lautus*	„	62	„
	6.	„ „ *denarius*	„	67	„
	7.	„ „ *auritus*	„	95	„
Passage Bed	8.	„ „ *cristatus*	„	99	„
Upper Gault.	9.	„ „ *varicosus*	„	71	„
	10.	„ *Kingena lima* and *Ammo. circularis*	„	69	„
	11.	„ *Am. rostratus*	„	65	„[1]

Upper Greensand (Passage-bed).

Zonal Fauna.—1. *Zone of Am. interruptus.*—This ammonite everywhere occurs at the base of the Gault when exposed. Associated with *Am. interruptus* are many species equally restricted as to range—*Pholadidea sanctæ-crucis* (*in wood*), *Trigonia Fittoni*, *Palæocorystes Stokesii*, *Hamites attenuatus*, *Belemnites minimus*, *Hippurites*, and *Buccinum gaultinum*, and the rare ammonite, *A. Roissyanus*. This Zone is 10 feet thick.

2. *Zone of Am. auritus.*—This may be considered the base of the Gault—a deep black clay, with *Aporrhais calcarata*, *Turrilites elegans*, and *Ancyloceras spinigerum*, which are not known above this horizon. The same may be said of the following species:—*Fusus iterianus*, *Cerithium trimonile*, *Narica cancellata*, *Corbula gaultina*, and *Nucula De Rancei*. They are peculiar or restricted to this bed. Four feet in thickness.

Bed 3. *The Crab or Crustacean Bed* = Light bed. Fawn-coloured clay, 4 feet 6 inches thick. *Palæocorystes Stokesii*, *P. Broderipii*, *Corbula elegans*, and *Inoceramus concentricus*. *Ammonites splendens* occurs here, but the Crustacea are the chief feature.

Bed 4. *Ammonites de la Ruei* (group *Cristati*).—*Dentalium decussatum* abounds here, and is the prominent fossil.

No. 5. *The Zone of Nautilus clementinus* (De Rance), or the Zone of *Am. lautus* (Price) = the *coral bed* of Price. The following species occur, and are peculiar to the Zone:—*Astarte Dupiniana*, *Funis cancellatus*, *Solarium albense*,

[1] For complete list of species, see Mr. Price's Memoir on the Gault, *loc. cit.*, pp. 44-81. To which are also added those occurring at Wissant, Ardennes, Meuse (Phosphate species), Larrivour, Saully, &c. (Aube et Yonne), Sainte Croix (Up. Gault), and Cheville (Mid. beds).

and *S. moniliferum*. Eight species make their first appearance in this bed, viz., *Cardita rotundata*, *Nucula Vibrayeana*, *Avellana inflata*, *Bellerophonia minuta*, *Solarium conoideum*, and *Phasianella Ervyna*.

No. 6. *Zone of Am. denarius*—"*the mottled bed*." Special to this Zone are *Fusus elegans*, *Rissoina Sowerbii*, *Turrilites Hugardianus*, and *Ammonites cornutus*.

No. 7. *Zone of Am. auritus*. The top bed of the Lower Gault, Lower Albien = *the dark bed*, 6 ft. 2 in., very fossiliferous (67 species), is especially rich in Gasteropoda, *Aporrhais Parkinsoni*, *Fusus indecisus*, *Avellana Dupiniana*, and *Cerithium Phillipsi*.

No. 8. *Zone of Am. cristatus*—"Junction or Passage-bed between the Upper and Lower Gault" = "*nodule bed*," 10 inches thick. This Passage-bed contains many species belonging to both divisions of the Lower and Upper Gault, and marks the total extinction of many Lower Gault forms, as well as the introduction of new ones. The Siphonostomatous Gasteropoda became extinct in this bed, and were succeeded by the Holostomata; many ammonites belonging to various groups occur here. *Am. Beaudanti* occurs in no other part of the Gault. The nodules in this Zone, like those at the base, No. 1, contain for the most part a *remanié* group of fossils.

The Lower Gault sea was favourable for the development of the Gasteropoda. Fifty-four species have been obtained from these beds, reaching their maximum in bed 7. Eleven of these species extend into the nodule bed No. 8.[1]

Out of 17 species of Gasteropoda found in the Upper Gault, 14 survived from the Lower. "Out of 85 species of Pelecypoda in the whole deposit, 45 became extinct in the Lower Gault or in bed 8." Taking the whole of the fauna of the Gault, Mr. F. G. H. Price obtained 292 species, 124 of which became extinct in bed No. 8, and 46 lived on into the Upper Gault. Fifty-seven new forms occur in the Upper Gault.

The following Ammonites amongst other species are peculiar to bed 8:—*A. splendens*, *A. Beaudanti*, *A. Brongniartianus*, *A. itierianus*, and *A. Selliguinus*, with 12 other genera and species.

No. 9. *Zone of Ammonites varicosus*. This Zone forms the base of the Upper Gault. *Inoceramus sulcatus* is the typical fossil of the Zone, and has *not been met with* in the Lower Gault; it reaches its maximum in this bed. *Am. varicosus* is abundant, and the characteristic form. These two shells determine and fix the base of the Upper Gault. *Ammonites lautus* of the group Dentati also occurs here; immediately below the hard seam at the top of the Zone, *Am. rostratus* (Sow.) makes its first appearance, thence ranging to the top of the Gault. *Scaphites æqualis*, *Pleurotomaria Gibbsii*, and *Avicula Rauliniana* first occur here.

No. 10. *Zone of Kingæna lima*. The clay of this Zone is homogeneous, hard, and pale-grey in colour, with few organic remains; *Plicatula pectinoides* is abundant. The large *Aporrhais* (*A. maxima*) was obtained from this bed, associated with *Pentacrinus Fittoni*, *Cidaris gaultina*, *Pinites Pricei*, and *Sequoia*, the oldest known representative of the genus. *Kingæna lima* is peculiar to this horizon. *Chelonia*, *Fish*, &c. occur also.

No. 11. *Zone of Ammonites rostratus*, 56 feet thick. Pale-grey marl rich in fossils. *Am. rostratus* occurs of *large* size, often having *Plicatula sigillina* adhering to it. *Am. Goodhalli* likewise attains considerable development; but few fossils are peculiar to this Zone—*Holospongia* and *Inoceramus Crispii* may be named.

Eastbourne Gault.—From Beachy Head eastwards, beyond the Pier, the Gault is exposed at low water. The uppermost bed, No. 11, of the Folkestone section, is here seen—that portion called "*The Middle Greensand of the Gault.*" Its junction with the sandy base of the Chalk marl (*Stauronema* beds) can be determined near the Martello Tower, No. 74. The bed (11) contains here 18 genera and 21 species. The chief forms are *Ammonites rostratus*, *Belemnites minimus*,

[1] *Vide* Mr. Price, *loc. cit.*, pp. 13-22, for complete analysis.

B. attenuatus, *Hamites armatus*, *Terebratula biplicata*, *Exogyra conica*, *Pecten orbicularis*, and *Dentalium decussatum*.

Inland, at St. Anthony's Tower, the *Junction* or Passage-bed of the Upper and Lower Gault (bed 8) is proved by the following species: *Ammonites varicosus*, *A. lautus*, *Bel. attenuatus*, *Nautilus Bouchardianus*, *Inoceramus sulcatus*, *Nucula bivirgata*, and the coral *Smilotrochus elongatus*.

Fauna of the Eastbourne Gault.—The fauna of the Gault of Eastbourne comprises 30 genera and 42 species, or *Pisces* $\frac{1}{4}$, *Cephalopoda* $\frac{4}{14}$, *Gasteropoda* $\frac{3}{4}$, *Pelecypoda* $\frac{1}{2}\frac{1}{3}$, *Brachiopoda* $\frac{1}{3}$, *Cirripedia* $\frac{1}{3}$, *Crustacea* $\frac{1}{3}$, *Echinodermata* $\frac{1}{4}$, *Rhizopoda* $\frac{1}{4}$, or $\frac{3}{4}\frac{0}{2}$ species. The rarer forms are *Cidaris Gaultina*, *Aporrhais carinata*, *Pollicipes unguis*, and *Nautilus inæqualis*?

Gault in the Isle of Wight.—The Gault here attains a thickness of about 100 feet. It is a bluish-black clay, sandy in parts, and slightly micaceous; well exhibited at Black-Gang, Wroxhall, parts of the Undercliff near Ventnor, Bonchurch, and Compton Bay.

The presence of *Ammonites rostratus*, *Inoceramus sulcatus*, *Solarium ornatum*, and *Belemnites ultimus*, &c., determines it to be Upper Gault.

Dorsetshire.—The Gault of Golden Cap, Stonebarrow, Black Ven, and Pinhay Cliff near Lyme Regis, is a dark-grey micaceous clay resembling the Lias on which it rests.

At Black Ven, where it is best exposed, it is divided from the "*Cowstones*" above (which may be Upper Greensand) by a few feet of yellow sand. Comparison of the fossils from Black Ven with those of Folkestone tends to correlate the Dorsetshire Gault with the Lower Gault of Folkestone, rather than with the Upper.[1]

The Blackdown beds, according to evidence afforded through published lists, appear to be a mixture of Upper and Lower Gault forms, representing, probably, both divisions of the Gault.

It is possible, however, that the Blackdown beds are equivalent to the lower part of the Upper Greensand (probably Upper Gault).

Fauna of the Dorset Gault.—Thirty-three genera and 33 species occur in the Gault of Black Ven and Golden Cap, and 19 genera with 19 species have been obtained from the "*Cowstones*" of the former section, but not a single species is common to the two series in the same section; in both cases only 1 species illustrates each genus, or $\frac{3}{3}\frac{3}{3}$ and $\frac{1}{1}\frac{9}{9}$. This is remarkable, considering that the genera are all of ordinary types; little search has, however, yet been made.

The typical "**Cowstones**" species are *Hoploparia longimana*, *Necrocarcinus Bechei*, *Cardium gentianum*, *Thetis Sowerbyi*, *Trigonia alæformis*, *T. scabra*, *Cytherea plana*, *Turritella granulata*, and *Pleurotomaria Rhodani*.

At Lulworth Cove the Gault is only about 15 feet in thickness, and represents the upper beds, resembling the Black Ven section. At Seend in Wiltshire the Gault is 80 feet thick, and south of Swinton it rests unconformably on the Kimmeridge Clay.

[1] Mr. De Rance asserts that 32 per cent. of the fossils from the Cowstones occur in the Folkstone Gault. A list, by Mr. De Rance, of fossils occurring in the Cowstones of Black Ven, shows that 27 species out of 33 are the same as those found in the Lower Gault of Folkestone, or between Beds 1 and 8.

Gault of Mid-England.

Oxfordshire Gault.—Culham, near Oxford, exhibits 20 feet of Lower Gault, resting upon Kimmeridge Clay, with the intervention of a thin bed of sand.

Oxford Fauna.—In this section the following fossils have been obtained:—*Ammonites dentatus, Am. lautus, Belemnites minimus, Solarium conoideum, Nucula pectinata, Inoceramus concentricus, Plicatula pectinoides,* and *Cyclocyathus Fittoni.* Below this unequivocal Gault occurs (in the same section) the Kimmeridge Clay, which, but for organic remains, could not lithologically be distinguished from the Gault above.[1]

In Bedfordshire, from Arlesey (north of Hitchin), as far as Barton, and also between the villages of Barton and Sharpenhoe, the Gault continues to be about 200 feet in thickness.[2]

Bedford Fauna.—At Ford near Dinton, north-west of Tring,[3] Mr. W. Keeping obtained 26 genera and 32 species, the more important forms being *Ammo. varicosus, A. inflatus = rostratus, A. lautus, A. cristatus, Hamites attenuatus, Nautilus Clementinus, Solarium ornatum, Pleurotomaria Rhodani, Aporrhais carinata, Inoceramus sulcatus, Trochocyathus Harveyanus,* and *T. conulus.* Many fish-remains. These species indicate an Upper Gault fauna.

Cambridgeshire Gault.—The remarkable deposit of phosphatic nodules, locally called "*coprolites,*" containing rolled fossils, nodules of phosphate of lime, and grains of glauconite, lies at the base of the Chalk marl, reposing upon the eroded surface of the Gault.[4]

Phosphatic Bed.—The presence of these large quantities of glauconitic grains in the phosphatic masses of the Cambridge bed arises from the denudation of a thick seam of Greensand, which occurs near the top of the Gault, in bed 11. The fauna of the Cambridge Gault is the same as that of Folkestone. Over 40 per cent. of the Fossils from the Cambridgeshire nodule-beds (or Cambridgeshire Greensand) are the same as those of the Upper Gault of Folkestone.[5]

Thickness of the Cambridgeshire Gault.—The Gault of Cambridge is from 110 to 130 feet thick, and increases in thickness in a S.-W. direction. At Bassingbourne it is from 150 to 175 feet thick; at Guilden Morden, 175 to 190 feet; at Arlesey and Hitchen 204 to 214 feet thick, thus showing an increase of 100 feet between Cam-

[1] Phillips: Geol. of Oxford and Valley of the Thames, pp. 427–8.

[2] A. J. Jukes-Browne: Q. J. Geol. Soc., vol. xxxi. p. 262, &c.

[3] Described by Mr. Walter Keeping, M.A., F.G.S., with a list of 32 species illustrating 26 genera. Price on the Gault, *loc. cit.*, p. 30.

[4] Prof. Bonney in 1872 in his paper on the Upper Greensand or Chloritic Marl of Cambridge (Geol. Association), and Mr. Jukes-Browne in 1875, *loc. cit.*, have both believed that the so-called Upper Greensand is the *débris* of the Upper Gault—the term "Cambridge Greensand" being now adopted to receive these beds. Mr. Price, from examination of the Fossils, states that they result from the denudation of the beds No. 10 and 11 of the Upper Gault.

[5] Mr. Price is of opinion that the Upper Greensand was never deposited in Cambridgeshire, and that this so-called Upper Greensand represents a period of great denudation during the deposition of the Chalk Marl. It forms the Junction-beds between the Upper Gault and the Chalk Marl.

bridge and Arlesey. Passing northwards at Norwich it has a thickness of 36 feet; and has died out before reaching Lynn.

In Mr. Jukes-Browne's paper,[1] the following thicknesses of the Gault are given, as occurring in the Coprolite Pits along a given line, N.E. to S.W.:—

	Ft.		Ft.
Horningsea and Cambridge	110	to	130
Grantchester	115	„	130
Haslingfield	130	„	160
Barrington	140	„	160
Wimpole	170	„	185
Bassingbourne	150	„	175
Guilden Morden	175	„	190
Ashwell	185	„	205
Arlesey and Hitchen	204	„	214

Fauna and Flora.—The fauna and flora of the Gault of England number 159 genera and 410 species. The 15 classes and their fauna are expressed in the following table:—

Plantæ	2 genera and 4 species.		
Spongia	2	„	2 „
Rhizopoda	21	„	59 „
Actinozoa	11	„	17 „
Echinodermata	5	„	7 „
Annelida	2	„	5 „
Cirripedia	2	„	4 „
Crustacea	14	„	25 „
Polyzoa	3	„	4 „
Brachiopoda	5	„	10 „
Pelecypoda	38	„	85 „
Gasteropoda	31	„	91 „
Cephalopoda	12	„	72 „
Pisces	6	„	7 „
Reptilia	5	„	5 „

The 12 *genera* of the Cephalopoda are important factors, and in no other formation are they so numerous and important as in the Cretaceous Rocks. Their importance requires separate generic analysis.

Ammonites 35 species, *Hamites* 12, *Helicoceras* 4, *Nautilus* 3, *Ptychoceras* 1, *Scaphites* 2, *Turrilites* 6, *Ancyloceras* 2, *Baculites* 1, *Anisoceras*, 2, *Conotheuthis* 1, and *Belemnites* 3 species.[2]

Foreign Equivalents.

Wissant, N.E. of Cape Grisnez in the Bas-Boulonnais, contains the finest and most exposed sections of the Gault in Northern France, similar in every respect to those of Folkestone and East-Wear Bay, but

[1] "On the Relations of the Cambridge Gault and Greensand," Q. J. Geol. Soc., 1875, vol. xxxi. p. 261; also see Mem. Geol. Survey, "Geol. of the Neighbourhood of Cambridge," map 51, S.W. by W. H. Penning, and A. J. Jukes-Browne, and R. Etheridge, pp. 13–19.

[2] The Cephalopoda of the British Cretaceous Rocks number 15 genera and 246 species, viz.—The Neocomian, 67 species; Gault, 72; Upper Green Sand, 31; Chalk Marl, 55; Lower Chalk, 61; and the Upper Chalk, 27. These 246 species make 313 appearances, showing that few species are common to the several horizons, but have limited vertical range.

*

not so thickly developed. The Gault, as at East-Wear Bay, forms the floor over which the sea washes the cliffs. Wissant forms the north-east side of the Weald Basin of France. The zonal divisions adopted at Folkestone for the Gault are equally applicable to this area.

The Zones of *Ammonites mammillaris* and *Am. interruptus* (bed 1) are here associated, but physically the beds are so similar that it is difficult to separate them.

D'Orbigny determined that the Gault of Wissant separates the Lower Gault, beginning as we do in the Zone of *Am. mammillaris*, which rests immediately upon, or is in contact with, the "Folkestone beds," or the highest member of the "*Upper Neocomian*" series.

Dr. Barrois, in his paper, "Sur le Gault,"[1] at first believed the upper part of the "Lower Greensand" Folkestone beds (Up. Neocomian) to be our Zone of *Sables Verts à Am. mammillaris*. He also "considered that the *A. mammillaris* Zone corresponded to a period of great extension in the Gault sea of the Paris Basin." Subsequent research has, however, modified Barrois' views,[2] and he now considers the Zone of *Am. mammillaris* to belong to the Gault, and not to the Upper Neocomian.

Mr. Price, with much reason, refers the Gault of Wissant in its deposition to the same basin as that of Folkestone, the present separation by the Channel being only a geographical accident—the Bas-Boulonnais series being the south-eastern edge of the Wealden and higher Cretaceous series.

Dr. Barrois adopts the following divisions of the Gault:—[3]

Upper.	*Zone à Ammonites mammillaris* . .	Sables Verts.
	Zone à Ammonites interruptus . .	Argile inférieure; Grès des Drillons; Argile des Drillons; Sable de Frécambault; Argile à *Epiaster Ricordeanus*.
Lower.	*Zone à Ammonites inflatus = rostratus*.	Argile Glauconieuse de Sancerre; Ocre de Puisaye; Gaize de l'Argonne; Gaize supérieure de Réthel; Argile supérieure de Wissant, &c.

Correlation.—The geographical extension of the Zone *Am. mammillaris* is greater than that of the preceding Aptian (or Neocomian) beds, but before the conclusion of the deposition, ascending oscillation or movement set in, and continued until the close of the sedimentation containing *Ammo. Lyelli*[4] (above the *Am. mammillaris* Zone). The Zone of *Am. inflatus* (*rostratus*) corresponds to a fresh invasion of the sea (descending oscillation), this inference being drawn from the fact

[1] Annales de la Soc. Géol. du Nord, 1874.

[2] L'Age des Folkestone-beds du Lower Greensand. Soc. Géol. du Nord, 1875.

[3] Mémoire sur le Terrain Crétacé des Ardennes et des régions voisines. Lille, 1878.

[4] A French form allied to *mammillaris*, but not known in England.

of its geographical distribution varying from the preceding deposits. The classification is simpler, if we carry the Gault up to where the Chert series of the Upper Greensand with *Pecten asper* (where these beds are present), and the sandy beds of the Chalk marl begin, than if we limit its extent to the Junction-bed, No. 8, and place the marly beds of the Upper Gault, Nos. 9, 10, and 11 (the Zone of *Am. inflatus*) (= *rostratus*) in the Cénomanien, as adopted by Barrois.

M. D'Orbigny divided the Gault into two portions:

"The lower beds, represented by the clays of the Aube, Wissant, the Meuse, and Ardennes.

"The upper those of the Meuse, Ardennes (Machéroménil, Saulces-aux-Bois), and the Chloritic marl of Wissant. The Upper Gault of English and Swiss geologists corresponds to the Gaize of Argonne."

The bed of phosphatic nodules of Talmats in Argonne equals the Cambridge coprolite or nodule bed. "The Gault does not extend to the North of Argonne. The Department of the Aube has been extensively worked, and the chief localities are Dienville, Gérodot, Gaty, Maurepaire, Brienne, and Ervy." (Price, *loc. cit.*)

The following is the correlation of the Zones of the Gault of the Northern part of the Aube with those of Folkestone, as prepared by M. A. Delatour[1]—reading upwards:—

Upper Neocomian.—*Zone of Am. mammillaris*—Sables Verts inférieurs.			
Lower.	Bed	I. à Am. interuptus = Zone of *Bel. minimus.*	Gault, 60 m.
	,,	II. à Am. auritus, var. = ,, *Am. mammillaris.*	
	,,	III. à Crustacea = *Crustacea.*	
	,,	IV. à Am. Delaruei }	
	,,	V. à Am. lautus } = *Am. interruptus.*	
	,,	VI. à Am. denarius }	
	,,	VII. à Am. auritus = Zone à *Am. splendens.*	
Junction Bed		VIII. à Am. cristatus = Conglomérat ferrugineux.	
Upper.		IX. à Am. varicosus = Zone à *Am. varicosus.*	Argiles Cénomaniens, 70 m.
		X. à Kingena lima = *Kingena lima.*	
		XI. à Am. rostratus = *Am. rostratus.*	

Switzerland.—The Gault of Switzerland is divided into three portions, and obtains in much the same manner as in England—

1. The Gault Inférieur. Yellowish sand with *black fossils.*
2. Gault Moyen. Red and black marls with *pyritised fossils.*
3. Gault Supérieur, consisting of greensands mingled with *yellow marls.*

The typical sections of the Gault are at Vraconne near Sainte-Croix, Col de Cheville, Perte du Rhône, &c.

[1] In Mr. Price's memoir, "The Gault," p. 40, is given M. Delatour's table of the principal fossils from the Gault of the Aube (partie nord), collected from the different Zones (11). He enumerates 40 genera and 76 species, amongst them 17 species of Ammonites (12 of the 17 being British). In this table, beds 1–7 are Lower Gault, bed 8 the Junction-bed, 9, 10, and 11 Upper Gault (Cenomanien of the French geologists).

Pictet and Campiche have described the Gault fauna at Vraconne. Professor E. Renevier has done the same for the fauna of other localities, and has named the Gault Supérieur or Grès Verts Supérieurs "Vraconnien."

CHAPTER XLVIII.

UPPER GREENSAND AND CHALK.

Upper Greensand.

Synonymes.

Cenomanien (Craie Glauconieuse).

Firestone.
Malm Rock. } Merstham Beds.

Cenomanian or Upper Greensand.—The Upper Greensand was first examined, and its position understood, in Wiltshire, where it consists of green, grey, and irony sands immediately subjacent to the Chalk, and affording facilities for the collected water of that thick deposit passing downward to the Gault. The green grains, however, then assumed to be characteristic of these strata, are now known to occur in older rocks. The Upper Greensand under London and in Bedfordshire appears to be the representative of the beds at Merstham in Surrey, at Beer in Dorsetshire, and round the Weald of Surrey and Sussex; the Malm Rock, which is certainly coeval with the Wiltshire Greensand, and also with the Merstham firestone, contains green grains, and at Beachy Head changes to nearly the ordinary type of the Greensand of Wiltshire. From these considerations we are fully justified in regarding the Upper Greensand as intimately connected with the Lower and commonly argillaceous part of the Chalk (Chalk Marl), just as the Calcareous Grit is with the Coralline Oolite. In particular places, mechanical causes gave a predominance to its sandy character, and in others the abundance of organic remains impresses it with a particular zoological type. This accords with its general character through France, where it is associated with the lower argillaceous Chalk under the title of *Glauconie crayeuse*. According to this classification, the Upper Greensand or Firestone beds form a nearly continuous base for the Chalk from Lynn in Norfolk to Dorsetshire, and round the whole of the Weald of Kent and Sussex, yielding organic remains at intervals. The thickness of this mass of sand is quite irregular, varying from a few feet to about 100 feet.

The Upper Greensand succeeds the Gault in almost every locality where the latter occurs; physically it consists of greenish-grey sand and sandstone, the green-grained beds being charged with glauconite grains (composed of hydrous silicate of iron, alumina, and

PLATE XXVII.

CRETACEOUS FOSSILS.

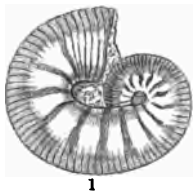
(*Upper Greensand and Chalk.*)

1. *Scaphites æqualis* (Sow.) Lower Chalk, Chalk Marl. Lewes, Evershot, Chardstock.
2. *Ammonites* (*Acanthoceras*) *Rhothomagensis* (Brongn.) Lower Chalk. Sussex, Hampshire, &c.
3. *Turrilites costatus* (Lam.) Lower Chalk. Hamsey, Folkstone, Compton, Norwich.
4. *Inoceramus Cuvieri* (Sow.) Upper and Lower Chalk. Lewes, Royston, Petersfield, &c.
5. *Pecten Beaveri* (Sow.) Lower Chalk. Kent, Wilts, Sussex, Norfolk, &c.
6. *Lima Hoperi* (Sow.) Upper Chalk. Norwich, Lewes, Surrey, Kent, &c.
7. *Ostrea vesicularis* (Lam.) Upper Chalk. Kent, Sussex, Norfolk.
8. *Lima spinosa* (Sow.) Lower and Upper Chalk. Norfolk, Sussex, Kent.
9. *Pecten* (*Janira*) *quinquecostatus* (Sow.) Lower Chalk, Gault, and Neocomian—*passim*.
10. *Terebrirostra lyra* (Sow.) Chloritic Sand and Upper Greensand. Warminster.
11. *Terebratula biplicata* (Sow.) Upper Greensand (Cambridge Greensand). Cambridge, Warminster, &c.

PLATE XXVII.

CRETACEOUS FOSSILS.

(Upper Greensand and Chalk).



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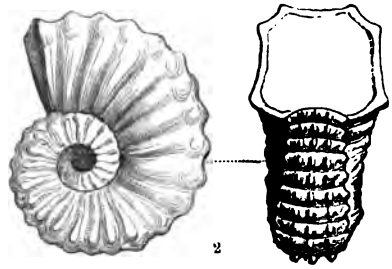

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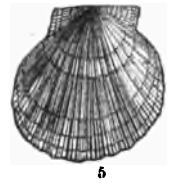

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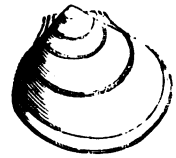

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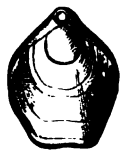

11

7

potash). The thickness varies considerably, as in all arenaceous deposits. Around the Wealden area it averages about 60 feet; at Petersfield it is 80 feet thick; at Eastbourne 40; Nutfield 40; and Godalming 50 feet. It is thinly exposed at East Wear Bay, Folkestone, not exceeding there 20 feet in thickness.

Under the name of "Upper Greensand" were formerly comprised strata now known to have little real meaning or significance in this connection, but belonging to different horizons in the Cretaceous series. On the Continent and in Britain the classification of this division has, therefore, been entirely re-constructed.

The researches of Dr. Barrois, of Messrs. Hébert, Renevier, Coquand, &c., have shown that (as originally defined by Fitton, Webster, and others) the Upper Greensand has no such distinctive fauna as was then supposed.

Subdivisions.—The Upper Greensand appears to be naturally divisible into two groups of different lithological structure—

1. The Lower, containing *Ammonites rostratus*, Sow. (*A. inflatus*, Sow.)
2. The Upper, characterised by *Pecten asper*.

Both these types are well developed in *Devonshire*, *Somersetshire*, and *Wiltshire*.

Fauna of the Blackdown Beds.—The Blackdown beds at their lower portion are closely allied to the Gault, and contain a remarkable fauna, many of the species not occurring in any other horizon. The most abundant found at Blackdown are *Ammo. Goodhalli* and *Am. varicosus*, *Trigonia alæformis*, *T. scabricola*, *Cytherea plana*, *Cyprina angulata*, *Cardium Hillanum*, *Lucina orbicularis*, *Corbula elegans*, *Thetis gigantæa*, *Exogyra conica*, *Lima semisulcata*, *Pecten quadricostatus*, *Gervillia anceps*, *Inoceramus concentricus*, *Cucullæa carinata*, *Pectunculus umbonatus*. Amongst the Gasteropoda the following species are important:—*Murex calcar*, *Natica gaultina* (*N. canaliculata*, Sow.), *Aporrhais Parkinsoni*, *Dimorphosoma* (*Aporrhais*) *calcarata*, *Turritella granulata*, and *Actæon affinis*.

Fauna of the Warminster Beds.—The upper series or Warminster beds belongs to the Zone of *Pecten asper* of Barrois, and *Holaster nodulosus* of Hébert, and contains *Am. varians*, *Am. Mantelli*, *Belemnites ultimus*, *Pecten asper*, *Ostrea frons* (*carinata*), *Terebratula biplicata*, *T. squamosa*, *Rhynchonella compressa*, and *R. latissima*. *Peltastes clathratus*, *Discoidea subuculus*, *Salenix*, and *Pseudodiamæ*. Dr. Duncan has named and described an extensive coral fauna from the Haldon beds;[1] out of the 20 species described 10 are new. The Blackdown fauna amounts to 90 genera and 196 species. About 50 species are common to (or occur at) Haldon also; of these 50 species 37 are *Pelecypoda*, and 8 *Gasteropoda;* to the *Annelida* and *Brachiopoda* belong 1 species each.[2]

Chalk of Cambridgeshire.

Dr. Barrois applies to the English Chalk the same zonal classification which has been so carefully worked out in France by Professor Hébert and himself. These zones are arranged under three great sections, viz.:—

1. *Cenomanian*, = Lower;
2. *Turonian*, and = Middle;
3. *Senonian*, = Upper;

[1] Q. Jour. Geol. Soc., vol. xxxv. p. 90. Most of the species described are from the cabinet of Mr. Vicary of Exeter.

[2] For description of the Blackdown beds, see paper by Rev. W. Downes, Q. J. Geol. Soc., vol. xxxviii. p. 75; Fitton "On the Strata between the Chalk and Oxford Oolite," Trans. Geol. Soc., vol. iv. pp. 239–42.

which are correlative with the *Lower*, *Middle*, and *Upper* of Britain.[1] The Geological Survey, again, through the work of Mr. A. Jukes-Browne and Mr. Penning in Cambridgeshire, divides the Chalk into 4 clearly-defined stages, two of which were before established by Mr. Whitaker (viz., "the *Chalk Rock*, and *Totternhoe Stone*.") Between these main boundary lines 10 definite *Palæontological Zones* are also recognisable.

The Ten Palæontological Zones of the English Chalk.

Lower.	1. Cambridge Greensand, "or Coprolite bed."
	2. Chalk Marl, or Zone of *Rhynchonella Martini*.
	3. Totternhoe stone.
	4. Zone of *Holaster subglobosus*.
Middle.	5. Melbourn Rock.
	6. Zone of *Rhynchonella Cuvieri*.
	7. Zone of *Terebratula gracilis*.
	8. Zone of *Holaster planus*.
	9. Chalk Rock.
Upper.	10. Zone of *Micraster cor-bovis*.

1. *The Cambridge Greensand.*[2]—This is the homotaxial equivalent of the Chloritic marl, and forms the basement bed of the Chalk marl. The thin noduliferous Cambridge beds are composed of nodules inclosed in a matrix of *Glauconitic marl*, which passes up into grey chalky marl, or marly chalk.

Fauna of the Cambridge Greensand.—The greater part of the fossils contained have been *derived from the Gault below*. No less than 123 genera and 293 species have been recognised, and numerical analysis shows the following zoological grouping:—

REPTILIA $\frac{1}{11}$ (some of them are MS. names); AVES $\frac{1}{2}$; PISCES $\frac{1}{8}$; CEPHALOPODA $\frac{2}{17}$, generically these are *Belemnites* $\frac{1}{2}$, *Conoteuthis* $\frac{1}{7}$, *Ammonites* $\frac{1}{13}$, *Scaphites* $\frac{1}{5}$, *Turrilites* $\frac{1}{4}$, *Helicoceras* $\frac{1}{2}$, *Ancyloceras* $\frac{1}{2}$, *Hamites* $\frac{1}{2}$, and *Baculites* $\frac{1}{2} = \frac{13}{17}$; GASTEROPODA $\frac{2}{11}$, *Bivalvia* $\frac{2}{11}$; BRACHIOPODA $\frac{2}{7}$; CRUSTACEA $\frac{1}{14}$; CIRRIPEDIA $\frac{1}{2}$; ECHINODERMATA $\frac{7}{13}$; ACTINOZOA $\frac{2}{4}$; AMORPHOZOA $\frac{1}{12}$.

The fauna belonging to the bed itself (or not derived) comprises 44 genera and 73 species. Zoologically defined, it includes *Reptilia* $\frac{1}{11}$, *Fish* $\frac{2}{7}$, *Cephalopoda* $\frac{1}{2}$, *Gasteropoda* $\frac{1}{2}$, *Bivalvia* $\frac{8}{13}$, *Brachiopoda* $\frac{2}{7}$, *Echinodermata* $\frac{6}{13}$, *Annelida* $\frac{2}{3}$, *Actinozoa* $\frac{2}{4}$, *Spongida* $\frac{1}{2} = \frac{12}{13}$.[3]

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[1] In 1870, Mr Caleb Evans, after careful study and investigation, was the first to point out the value of a Zonal classification for the English Chalk. He establishes 6 sub-divisions or Zones, grouping them under 3 headings—1. The chalk with bands of flint; 2. The chalk with bands of marl; and 3. The grey chalk and chalk-marl. Mr. Evans' 6 divisions are—1. The Oxstead beds; 2. The Lower Marden Park beds; 3. Upper Marden Park beds; 4. The Whiteleaf beds; 5. The Henley beds; and 6. The Riddlesdown beds at the top.

[2] *Vide* Jukes-Browne, Q. Jour. Geol. Soc., vol. xxxi. p. 272.

[3] *Ib.*, pp. 305, 313. The fossil contents of the Cambridge Greensand are divisible into 2 groups, exhibiting differences in their Palæontological affinities as well as their states of preservation and fossilisation; one group of fossils has been derived from the Gault below, and the other belongs to the bed itself. For list of Fossils, see "Geol. of the Neighbourhood of Cambridge, expl. of $\frac{1}{4}$ sheet, 51 S.W. and part of N. 51 W.;" W. H. Penning and A. J. Jukes-Browne; Appendix by R. Etheridge (Mem. Geol. Survey), pp. 29–30. Reptilia $\frac{1}{11}$, Fish $\frac{1}{7}$, Cephalopoda $\frac{1}{2}$, Bivalves $\frac{8}{11}$, Brachiopoda $\frac{4}{11}$, Echinodermata $\frac{6}{13}$, Crustacea $\frac{1}{2}$, Annelida $\frac{1}{2}$, Actinozoa $\frac{2}{3}$, Protozoa $\frac{1}{2}$ (in memoir).

2. *Chalk Marl or Zone of Rhynchonella Martini.*—Marly series about 60 feet thick in Cambridgeshire; not very fossiliferous, comprising 7 genera and 20 species only, and 14 of these occur also in the Cambridge Greensand below. This sub-division is well exposed at East-Wear Bay, near Folkestone, also in the Isle of Wight (100 feet thick).

Fauna of the Chalk Marl.—The chief fossils are *Plocoscyphia meandrina, Holaster lævis, Rhynchonella Martini, Inoceramus striatus, Plicatula inflata, Ammo. cenomanensis, A. falcatus, A. Mantelli, A. navicularis, A. varians, Scaphites æqualis, Turrilites costatus.*

The fauna of the Chalk Marl of the Folkestone area (or beds Nos. I. and II. of Mr. Price) numbers 35 genera and 57 species.

The known fauna of the 5 Zones of the Grey Chalk, arranged by Mr. Price in these beds in East-Wear Bay, represents the life of those horizons for South Kent and the south of England generally, and also largely applies to the Chalk of Cambridge. Sixty-two genera and 95 species occur in these 5 *divisions* of the Grey Chalk, 21 species are common to the two groups of strata (Chalk Marl and Grey Chalk), and only 1 species (*Ostrea vesicularis*) is common to the Chalk Marl and Lower Chalk.

3. *The Totternhoe Stone* (*Grey Chalk*).—A compact, grey, sandy limestone, with a fauna numbering from 80 to 90 species. The characteristic species are *Lima echinata, Pecten fissicosta, P. opercularis. Ammonites varians* and *A. cenomanensis* frequently occur also, with the remarkable shells *Scalaria fasciata* and *Pinna tegulata.* Burwell, near Cambridge, is the rich locality for the Totternhoe fauna. The Woodwardian Museum contains nearly every known form. Twenty-eight genera and 43 species are known. Comparatively few species are confined to the Totternhoe stone, the greater number of those which are most abundant individually ranging into the overlying Zone of *Holaster subglobosus.*

4. *Zone of Holaster subglobosus.*—The lower part of this horizon is everywhere characterised by the frequent occurrence of *Holaster subglobosus, H. trecencis, Discoidea cylindrica,* and *Ammonites Rhothomagensis.* Forty species have been determined from this Zone.

5. *Melbourn Rock. Middle Chalk.*—So called from the peculiar development at Melbourn, between Cambridge and Royston. *Inoceramus labiatus, Ostrea vesicularis, Lamna, Otodus,* and *Saurocephalus,* &c., with *Rhynchonella plicatilis* and *Ostrea vesicularis,* occur everywhere in this Zone. The Melbourn rock is a line of demarcation between or separating two different fossil assemblages, rather than a palæontological Zone. Only 12 genera and 16 species occur, nearly all the species met with in the Lower Chalk having disappeared. Out of the 90 species of Invertebrata [1] which have been obtained from the Lower Chalk of Cambridgeshire, only 8 have been found above the Melbourn rock. Seven others have a wider range; but no less than 74 species had died out or migrated during the interval between the deposition of the Lower and Middle Chalk.

6. *Zone of Rhynchonella Cuvieri.*—This division of the Middle Chalk corresponds to the Zone of *Inoceramus labiatus* of Barrois. Evenly bedded, white, hard Chalk, about 70 feet in thickness, with but few fossils. *Inoceramus mytiloides* (= *labiatus*), *Rhyncho. Cuvieri,*

[1] Q. Jour. Geol. Soc., vol. xxxiii. p. 431.

Galerites globosus, *G. subrotundus*, *Cidaris hirudo*, and *C. dissimilis* occur, but are rare.

7. *Zone of Terebratulina gracilis.*—Flints occur at certain horizons, mostly elongated and root-like, differing from the nodular flints of the Upper Chalk. *T. gracilis* is everywhere abundant, also *Galerites subrotundus*, and *Discoidea Dixoni* occurs occasionally. The thickness of this Zone cannot be less than 150 feet. *Echinodermata* and *Brachiopoda* abound. *Cidaris sceptrifera*, *Cyphosoma radiata*, *Holaster planus*, *Micraster breviporus*, and *M. cor-bovis* are in the upper beds, and *Cidaris dissimilis* and *Echinoconus subrotundus* in the lower. Seventeen genera and 26 species illustrate this Zone.

8. *Zone of Holaster planus.*—The Chalk of this Zone is soft and white, and about 50 feet thick, containing regular layers of black flints. The fauna, too, is very different from that of the Zone of *T. gracilis* below. Forms that become common in the Upper Chalk make their appearance here—such are *Cidaris sceptrifera*, *Cyphosoma radiata*, and *Spondylus* (Lima) *spinosa*. The Spongida through the *Ventriculites* are abundant for the first time, and also serve to distinguish this Zone from that of *T. gracilis*.

9. *Chalk Rock.*[1]—This really forms the uppermost bed of the Zone below. Both *Holaster planus*, *Ananchytes ovatus*, and *Micraster* (*?*) *breviporus* occur, associated with *Ammo. Prosperianus*, *Scaphites æqualis*, and certain univalve shells, *Turbo gemmatus* being common, as well as *Ventriculites*. This division is constant throughout the greater portion of the northern part of the London basin, dividing the Middle from the Upper Chalk. Sixteen genera and 24 species range through the Chalk Rock of Cambridgeshire.

The Middle Chalk of Cambridgeshire appears to be distinguished from the Lower and Upper by lines of erosion, one at the base of the Melbourn Rock, and the other at the top of the Chalk Rock, and by two zoological groups represented by such different species (in the Lower and Middle Chalk respectively) that they are of themselves sufficient to differentiate the two divisions, or the two faunas.

Fauna of the Chalk Rock.—These two groups are the *Cephalopoda* and the *Echinodermata*. Of the Ammonites alone, the *Lower Chalk* (or Cenomanian) contains a large number of species, but *not one* of them has yet occurred in the Turonian or Middle Chalk, which possesses its own special species; side by side they stand as follows:

Ammonites of the *Lower Chalk.*	Ammonites of the *Middle Chalk.*
Ammonites Rothomagensis.	*Ammonites nodosoides.*
„ *cenomanensis.*	„ *rusticus.*
„ *navicularis.*	„ *Woollgari.*
„ *Mantelli.*	„ *Carolinus.*
„ *Leweriensis.*	„ *peramplus.*
„ *varians.*	„ var. *Prosperianus.*
„ *falcatus.*	

[1] First described in 1861 by Mr. W. Whitaker, who indicated its position and occurrence at *the top of the Lower Chalk* in the counties of Wilts, Bucks, Oxford, and Berks. It forms a natural line of division between the Lower and Upper Chalk.

The following is a list of the chief species in the class Echinodermata belonging to the two faunas also. They are stratigraphically important:—

Lower Chalk.	*Middle Chalk.*
Holaster subglobosus.	*Holaster planus.*
,, *trecensis.*	,, *cor-avium.*
,, *nodulosus.*	*Cardiaster granulosus.*
Hemiaster Morrisii.	,, *pygmæus.*
Epiaster crassissimus.	*Micraster breviporus.*
Cidaris Bowerbankii.	,, *cor-bovis.*
,, *vesiculosa.*	*Cidaris subvesiculosus.*
,, *dissimilis.*	,, *dissimilis.*
,, *hirudo.*	,, *hirudo.*
Pseudodiadema ornatum.	*Cyphosoma simplex.*
,, *variolare.*	,, *radiatum.*
Echinocyphus difficilis.	*Echinoconus subrotundus.*
Peltastes clathratus.	,, *globosus.*
Salenia Clarkii.	*Salenia granulosa.*
,, *Austeni.*	,, *mespilia.*
Discoidea subucula.	*Discoidea minima.*
,, *cylindrica.*	,, *Dixoni.*

Many of the species which appear in the upper part of the Middle Chalk, also range up into the beds above, or the Chalk Rock, so that the greater palæontological break is at the base of the Melbourne Rock. The following species seem, however, to have died out in England before or during the formation of the Chalk Rock :—

Inoceramus Brongniarti, I. mytiloides, I. problematicus, Spondylus striatus, Rhynchonella Cuvieri—Ammonites (all *the species* named above (Lower Chalk), *Cidaris dissimilis, C. hirudo, Discoidea Dixoni, D. minima, Echinoconus globulus. E. subrotundus, Holaster planus, Cyphosoma simplex, Cardiaster pygmæus,* and *Salenia granulosa.*

10. *Zone of Micraster cor-bovis.*—This forms the base of the White Chalk with flints, or the true Upper Chalk, and is equivalent to the lower portion of the Senonian of D'Orbigny, with the characteristic *Micraster cor-testudinarium.*[1] Fourteen genera and 20 species occur in the Zone of *Micraster cor-bovis.*

In proceeding from Cambridge to Norfolk, we may pass from one area of deposition to another, for it is certain that the conditions which prevailed in the latter, or Norfolk, area during the earlier stages of the formation were very different from those which prevailed in the London basin.

In the singular but unique section at Hunstanton, subdivisions of the Zone of *Holaster subglobosus* are but feebly represented. The "sponge bed" may be the analogue of the so-called Chloritic marl, as it clearly forms the basement-bed of the Lower Chalk ; the occurrence of *Ammonites Rhothomagensis, Pecten Beaveri, Discoidea cylindrica,* and *Epiaster crassissimus* is suggestive of a higher horizon than that which is generally characterised by *Plocoscyphia mæandrina* with which they

[1] Dr. Barrois gives, as typical localities for this species, Cuckmere Haven in Sussex, Stockbridge, Winchester, and Pangbourne.

are associated.[1] Out of the 90 species (invertebrata) which have been obtained from the Lower Chalk of Cambridgeshire, only 8 have been found above the Melbourn Rock. Seventy-four species apparently died out during the interval between the deposition of the Lower and the Middle Chalk. Fifteen of these 74 species were Cephalopoda.

Norfolk (*Norwich*).—The Chalk exposed at Norwich belongs to the uppermost division of the English series. Most of the open sections yield the characteristic fossils of the Upper Chalk. There is little doubt that the Chalk of Norwich includes the highest beds occurring in Britain, and has close relation through its coral fauna with that of Faxoe, Rugen, and Cipley. At Carrow the Chalk is 1152 feet thick, and probably, on the whole, nearer 1200 feet. The Norwich Chalk has yielded 122 genera and nearly 200 species.[2]

TABLE LXXXIX.—*The Chalk Zones.*

	Whitaker, 1865–1872. (Bedford and Bucks).	Classification for Cambridgeshire, 1878.	Barrois, 1876. Berkshire and Oxfordshire.	
Upper Chalk.	White Chalk with flints.	Zone of *Micraster cor-bovis.*	*Zone of Micraster cor-bovis.*	Sénonien.
	Chalk Rock.	Chalk Rock.	*Zone à Holaster planus.* 6 to 10 feet.	
Middle Chalk.	White Chalk with few flints, but with thin layers of marl. 350 feet.	Zone of *Terebratulina gracilis.* 150 feet, in two divisions; the lower, Vandlebury beds.	*Zone à Terebratula gracilis.*	Turonien.
		Zone of *Rhynchonella Cuvieri.* 60 to 70 feet.	*Zone à Inoceramus labiatus.*	
	Hard-bedded Chalk with thin marly layers.	Melbourn Rock.	*Zone à Belemnites planus* (not identified in Berkshire).	
Lower Chalk. Grey Chalk.	Blocky Chalk with curved bedding. 60 feet.	Zone of *Holaster sub-globosus.* 80 feet.	*Zone à Holaster sub-globosus.* 150 ft. (in three divisions).	Cénomanien.
	Totternhoe stone. 10 to 15 feet.	Totternhoe stone.		
Chalk Marl.	Totternhoe marl. 80 feet.	Zone of *Rhynchonella Martini.* 50 to 60 feet.		
	?	Cambridge Greensand.	? Chloritic marl.	

[1] Mr. Jukes-Browne believes (and, we think, rightly) that the succeeding beds E. F. G. of Barrois are doubtless homotaxial with the Zone of *Holaster subglobosus*, when used in the sense in which Mr. Browne has defined it.

[2] "Outline of the Geology of Norfolk," by S. Woodward, 1833. See also "Geol. of the Country around Norwich" (Mem. Geol. Survey, England and Wales), by H. B. Woodward, F.G.S.

Chalk of the South of England.

Bed I.—In the south of England (Folkestone) the Chalk Marl rests immediately upon a bed of dark-greenish sand (with few fossils), which occurs between it and the Gault. This may represent the Upper Greensand. It passes at once into the Chalk Marl. Peculiar fossils occur. Eighteen species have been determined.[1]

Amongst them *Ammonites varians* (rare), *Pecten orbicularis*, *Plicatula inflata*, with the sponges *Stauronema Carteri*, *S. lobata*, *Hylospongia*, and *Plocoscyphia meandrina*.

Bed II.—Succeeding this first Chalk-marl bed is the true or hard Grey series, with a few green grains near the base. It is about 10 feet thick, and contains several bands of sponges, viz.—

Plocoscyphia meandrina = *Brachiolites labrosus* and *Dendrospongia fenestralis*, which are confined to these hard bands. This chalk marl is highly fossiliferous, containing 32 genera and 50 species. The ammonites are *A. cénomanensis*, *A. falcatus*, *A. Mantelli*, *A. navicularis*, *A. nothus*, and *A. varians*.

This bed is the equivalent of the Craie Marneuse with *Plocoscyphia meandrina* of Barrois. The Chalk marl can be examined in East-Wear Bay, at Lydden Spout, where the whole of the *Grey Chalk* is seen *in situ*, having a thickness of 170 feet. Mr. Price divides the Grey Chalk into 3 zones and 5 beds.

1. Zone of *Ammonites Rothomagensis* contains 3 beds (III., IV., V.)
2. „ *Holaster sub-globosus* „ 1 bed (VI.)
3. „ *Belemnitella plena* „ 1 bed (VII.)

Bed III. is mottled, soft, grey, marly chalk, about 8 feet thick, containing—

Ammo. varians and *Am. Rothomagensis*, *Pecten Beaveri*, *Rhynchonella Mantelliana*, *Pseudodiadema variolare*, *Cidaris vesiculosa*, and 10 other species.

Bed IV.—The middle bed of the *Ammonites Rothomagensis* Zone, is 11 feet in thickness, in which occur—

Am. Mantelli, *A. Rothomagensis*, *A. Lewesiensis* and *A. varians*, *Pecten Beaveri*, and *Radiolites Moretoni*.

Dr. Barrois places this bed in his Zone of *Holaster subglobosus*.

Bed V. Grey Chalk.—Particularly rich in Gasteropoda, although only 2 feet 9 inches thick. The Lydden Spout spring issues from the top of these marly beds, and through this bed—locally called the "Cast Bed"—the "Spout" flows.

Mr. Price makes these 3 beds (III., IV., and V.) the Zone of *Ammo. rothomagensis* and *A. varians*, which equals Barrois's Zone of *Am. varians*. The Burwell stone of Cambridge may represent this bed (Totternhoe stone). This is the most highly fossiliferous division of the Lower Chalk. The fauna comprises 60 genera and 80 species (for species see Q. J. Geol. Soc., vol. xxxiii. p. 438).

[1] Q. Jour. Geol. Soc., vol. xxxiii. p. 434 (F. G. H. Price).

PLATE XXVIII.

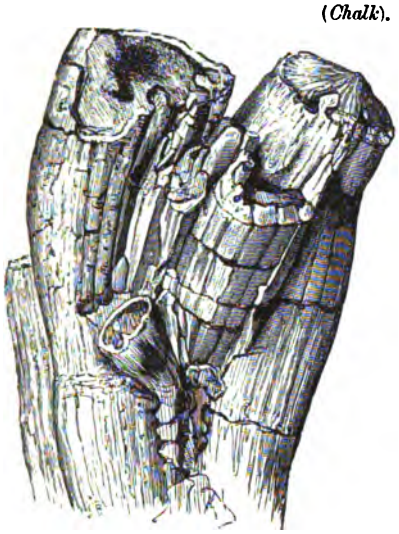
CRETACEOUS FOSSILS.

1. *Hippurites organisans.* Chalk of France.
2. ,, *bioculata.* ,, ,,
3. *Spherulites ventricosa.* ,, ,,
4. *Ostrea carinata* (Frons.) Chalk, Marl, &c.
5. Head (Upper and Lower Jaw) of *Mosasaurus.* From the Upper Chalk of Maestricht.

PLATE XXVIII.

CRETACEOUS FOSSILS.

(*Chalk*).

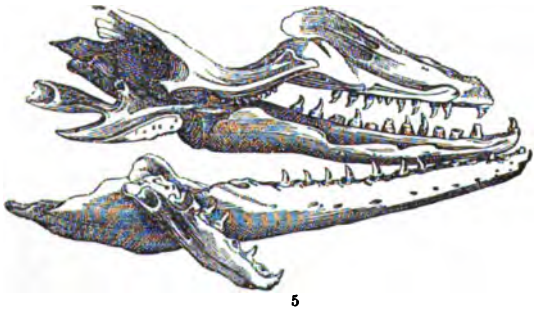


1

2

3

4



5

TABLE XC.—*The Zones of the Chalk Marl, Grey Chalk, and Lower Chalk, Folkestone.*

	Dr. Barrois.	Mr. F. G. H. Price's Divisions and Zones.		Drew (Whitaker, Mem. Geol. Survey, vol. iv.)	D'Orbigny.
		Upper Chalk.			
	Craie marneuse à *T. gracilis*, about 75 feet.	IX. Lower Chalk with *Inoceramus labiatus.*	Zone of *Echinoconus subrotundus* and *Terebratulina gracilis*, 118 feet.	Concretionary nodular Chalk, 73 feet.	Turonien, 150 feet.
	Craie noduleuse à *Ino. labiatus*, 75 feet.	VIII.	Zone of *Cardiaster pygmæus*, 32 feet.		
	Bel. plena Zone proper = Zone à *Bel. plena* (craie compacte).	VII.	Zone of *Belemnitella plena*, 4 feet.	Soft bed of 6 feet with Belemnites. Whitaker, p. 33.	
Assise à Hol. subglobosus, 169 feet.	Craie argileuse avec bancs durs à *Am. Rothomagensis.*	VI. Grey Chalk.	Zone of *Holaster subglobosus*, 148 feet.	White Chalk without flints, 138 feet.	
	Zone à *Ammo. varians.*	V.	2 feet 9 inches.	Chalk marl, thickness about 30 feet.	Cénomanien, 197 feet.
		IV.	11 feet. Zone of *Am. Rothomagensis.*		
		III.	8½ feet. *Am. varians.*		
	Craie marneuse à *Plocoscyphia meandrina.*	II. Chalk marl.	10 feet. Zone of *Plocoscyphia meandrina.*		
	Marine sableuse = Zone of *Pecten asper*, or Warminster beds.	I.	Zone of *Stauronema Carteri*, 14 feet.		
		Upper Gault.			

[F. G. H. PRICE (*loc. cit.*)

Chalk of the London Basin.

London Basin.—The Chalk of the London area is a marked feature, both as regards its scenery and its economic value, as one of the chief sources of the water-supply from deep wells in and around London. It forms the surrounding and underlying rock of the London Tertiary Basin, being everywhere present in considerable but varying thickness.[1] The Upper Chalk may be considered as the *conducting* medium, and the Lower Chalk as the *containing* reservoir for stowage of water. No clear division has, however, been established between the Upper and Lower Chalk of the London basin.

Surrey.—The Chalk of Surrey strikes through the country from West to East, having between Farnham and Guildford a high dip.

The following concise description will afford the chief information relative to the two received divisions of the Southern area :—

Chalk with Flints.	*a.* *White Chalk*, with layers of flints at intervals of from two to five feet, thickness about 200 feet = Nos. 2 and 3 of the Dover section.
	b. Chalk with hard nodules and scattered flints, about 25 feet. This may equal No. 4 of the Dover section.
Chalk without Flints.	*c.* White chalk, irregularly jointed, from 100 to 150 feet thick.
	d. Rather grey chalk, hard, slightly clayey, and making a good water-lime.
	e. Chalk marl, soft and of no great thickness.

A valuable contribution to our knowledge of the Chalk of Surrey has been published by Mr. Caleb Evans, based upon the sections exposed along the Surrey and Sussex railway between Croydon and Oxtead.[2] Mr. Evans gives the following threefold division of the Chalk :—

1. Upper Chalk 250 feet.	1. "*Purley Beds*, with layers of flint nodules and thin tabular flint. Zone with *Micraster cor-anguinum* in the Upper part, and *Inoceramus Cuvieri* below.
	2. "*Upper Kenley Beds*, with layers of flints nearer together than in the division above. Zone with *Micraster cor-anguinum* in the upper part, and *Ananchytes ovatus*, and *Spondylus* (*Lima*) *spinosus* below.
	3. "*Lower Kenley Beds*, with flints wider apart. Zone with *Holaster planus* and *Micraster cor-bovis*.
2. Middle Chalk.	4. "*Whiteleaf Beds.*—Thickly-bedded white chalk with layers of marl, few flints, and sometimes without any. Zone of *Inoceramus Brongniarti* and *Galerites albogalerus* (var. *sub-rotundus*), 75 feet.
3. Lower Chalk 190 feet.	5. "*Upper Marden Park Beds.*—White chalk with layers of marl, but without flints. Zone of *Ammonites peramplus* and *Inoceramus mytiloides*.
	6. "*Lower Marden Park Beds.*—Grey chalk and chalk marl. Zone of *Ammo. varians* and *Belemnitella plena*."[3]

The above 6 divisions yielded 45 genera and 86 species.

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[1] *Vide* Prestwich: "Geological Inquiry respecting the Water-bearing Strata of the Country round London," 8vo, 1850.

[2] Geologists' Association, 1870, 8vo, Lewes (read January 7, 1870).

[3] "The fossils above mentioned are not *entirely restricted* to the Zones in which they are said to occur, but it is in these beds that they are respectively the characteristic and prevailing forms" (*loc. cit.*)

			Cuttings.
Chalk with Flints.	The Purley Beds	Purley cutting 26 species North mouth 20 „	I. II. III. IV.
	South Riddlesdown . . .	25 „	
	Upper Kenley beds . . .	19 „	V.
	Lower Kenley beds . . .	12 „	VI.
Chalk with bands of Marl.	Whiteleaf beds . . .	19 „	VII. VIII. IX. X. XI.
	Upper Marden Park beds .	9 „	XII. XIII.
Grey Chalk.	Lower Marden Park beds .	21 „	

Vide Proc. of Geologists' Association, 1870, 8vo (Lewes).

The apparent correspondence of the Chalk of Surrey with the beds of Northern France and those of N.-Western Germany is at once interesting and significant, showing their deposition or sedimentation to have taken place in one hydrographical area, whilst very different conditions prevailed in the South of Europe.[1]

Zoological Classification of the Chalk of Surrey.[2]

1. Chalk with bands of flint 300 to 400 feet thick.	1. Purley.—*Micraster cor-anguinum* and *Echinoconus conicus* (upper part characterised by *Marsupites*).	
	2. Riddlesdown.—*Micraster cor-testudinarium.*	
	3. Kenley.—*Micraster cor-bovis* and *Holaster planus.*	
2. Chalk with bands of marl.	1. Whiteleaf.—*Inoceramus Brongniartii* and *Terebratulina gracilis.*	
	2. Upper Marsden Park.—*Inoceramus labiatus.*	
3. Hard white or yellow chalk.	Lower Marsden Park.—*Belemnitella plena.*	
4. Grey chalk or chalk marl.	Oxtead.—*Holaster trecensis* and *Ammonites varians* (*Holaster sub-globosus*, Barrois).	
Upper Greensand below.		

Kent.—In this county the Chalk broadly outcrops, and occupies a large area. The widest tracts are :—

1. In the neighbourhood of Dartford and Gravesend, where it stretches beyond the Thames into Essex.

2. On the south of Canterbury and Sandwich, without any outliers.

The Kentish Chalk is grandly exposed in the great cliff sections from the Isle of Thanet round to Folkestone, where every feature in its Southern-British development can be studied.

[1] Mr. C. Evans was one of the first observers who divided the English Chalk into Life Zones, already done to a large extent in France and Germany. The Anglo-Parisian Basin has received the careful study of M. Hébert, who divides the Chalk of that area into 4 groups. 1. The Upper Chalk—Pisolitic, and with *Baculites.* 2. White chalk, in 5 subzones—a. *Belemnitella mucronata*, b. *Bel. quadrata*, c. chalk with *Micraster cor-anguinum*, d. chalk with *Micraster cor-testudinarium*, e. chalk with *Holaster planus.* 3. Chalk of Touraine and *Hippurite* Limestone (Upper Zone wanting), chalk with *Inoceramus labiatus* and *Ammonites peramplus.* 4. Chloritic marl or chalk with chloritic grains (Upper Zone wanting), Zone with *Holaster subglobosus*, Zone with *Holaster sub-carinatus*, Zone with *H. suborbicularis.*

[2] *Vide* Caleb Evans. Geol. Assoc., 1870.

Margate Chalk.—The thickness of the Margate beds is about 80 feet. It is in places fossiliferous. The whole of the northern cliffs of the Isle of Thanet are in this group.

Broadstairs and St. Margaret's Chalk.—[Many flints and few organic remains.] For minute particulars of the coast from Margate to Dover, see Mr. Whitaker's paper in the Mem. Geol. Survey (vol. iv. pt. 1, pp. 30–36), where seven divisions or sections are described.

These are chiefly those of Wm. Phillips, but greatly added to through the researches of Mr. Whitaker of the Geol. Survey.[1] These seven are :—

1. [The Margate Chalk].
2. [The Broadstairs and St. Margaret's Chalk] (north-east of Dover).
3. [Chalk with many flints and many organic remains, or Chalk with interspersed flints].
4. [Chalk with few flints].
5. (Chalk without flints, but with many thin beds of organic remains).
6. (Chalk without flints and with few fossils).
7. (Grey Chalk) or Chalk marl (in part at least).

Inliers of Chalk (Kent).—Besides the coast sections there are five well-marked inliers, exposed through denudation. These occur at *Deptford*, *Greenwich*, *Plumstead*, *Abbey Wood*, and *Chislehurst*.[2]

The Chalk of the Isle of Thanet and Eastern Kent (Ramsgate, Margate, &c.) has also been carefully examined by Mr. G. Dowker,[3] and its fossil contents catalogued. The fauna numbers 39 genera and 76 species.

The Echinodermata and Protozoa of the North Kent fauna are both large and significant. The former class contains—*Marsupites* (3 species), *Ananchytes* (3), *Cidaris* (2), *Cyphosoma* (2), *Galerites* (2), *Micraster* (2), *Oreaster* (2), with *Pentacrinus* and *Echinopsis* 1 species each. The Protozoa (Spongidæ)—*Plocoscyphia* 1 species, *Cephalites* (1), *Choanites* (1), *Coscinopora* (3), *Manon* (1), *Ventriculites* (5), and *Siphonia* (1).

A comparison of the Kentish Chalk with that of Norfolk (Norwich and Diss), Lyme Regis, in Dorset, or with the Chalk of the Isle of Wight and Paris, shows that it is not always the Upper Chalk, but the lower divisions also, that have thinned away.

The following tabular statement shows important results, determined through deep borings undertaken to prove the thickness of the Lower Chalk between Dover and Calais. The borings were near High Light, South Foreland, on the English coast, and 4 miles south-west of Calais on the French coast, both below high-water mark :—

[1] The junction of the Upper and Lower Chalk is exposed on Westerham Hill, half a mile south of Gray's Farm, and again at Wrotham. The most complete account of the Chalk of Kent, especially with reference to the coast, is by Mr. W. Phillips. (Trans. Geol. Soc., ser. I. vol. v.) See also "Geol. of England and Wales," by Conybeare and Phillips, p. 90, &c.; and Dowker "On the Chalk of Kent," Geol. Mag., vol. vii., 1870.

[2] See Whitaker, *loc. cit.*

[3] Geol. Mag., vol. vii., 1870.

TABLE XCI.—*Showing Relative Thicknesses of the Chalk.*

			Feet.
At South Foreland	Upper Chalk	175 ft.	
,, ,, ,,	Lower	295	
			470
At Calais	Upper Chalk	270 ft.	
,, ,,	Lower	480	
			750
Isle of Wight (estimated)	Upper Chalk	1200 ft.	
,,	Chalk (no flints)	200	
,,	Chalk marl	80	
			1480

Norwich.	Feet.	Diss.	Feet.
Chalk with flint 6 or 7 ft. apart	483	Chalk, few flints marly	100
Chalk, soft and yellow	10	Chalk flints in layers	330
Hard flints 2 or 3 ft. apart	190	Grey Chalk with flints	60
Chalk without flints	350	Blue Chalk	20
Grey chalk	102		510
	1135		

Lyme Regis.		Grenelle, Paris.	
Chalk, numerous flints	50	Chalk with flints	1148
,, not so numerous	50	Lower Chalk	246
Without flint	40		1394
Do. green grains	25		
	165		

The section at Harwich	Chalk with flints	690	
	,, without flints	198	
		888	888

These sections show that the Upper Chalk is thickest at Norwich, Isle of Wight, Paris, and Harwich; while the Lower Chalk prevails at Dover, Calais, and Diss in Norfolk.

Chalk of Yorkshire.

The Chalk of Yorkshire forms a broad tract of country from the Vale of Pickering on the North to the Humber. It was not until Dr. C. Barrois had carefully studied the Chalk of this area, and brought it into palæontological comparison with other districts, that its true subdivisions and correlation were understood, so that the Zonal history of other areas could be applied to Yorkshire. The true Red Chalk of Hunstanton is characterised by *Ammonites inflatus* (Sow.) (*rostratus*), but this shell has not been found either in Yorkshire or Lincolnshire.[1]

The accompanying table shows the subdivisions of the Chalk of Yorkshire.[2]

[1] The Red Chalk of Speeton represents the whole of the Gault. *Am. Auritus* occurs commonly at Hunstanton and Lincolnshire (a Lower Gault fossil at Folkestone.)

[2] Consult an able communication upon the Chalk of Yorkshire by Prof. J. F. Blake, in the Proc. of the Geologists' Association, vol. v. pp. 232–270. Also see Phillips' "Geol. of Yorkshire."

TABLE XCII.—*Subdivisions of the Yorkshire Chalk.*

		Lithology.	Palæontology.	Thickness Feet.
Upper Chalk.	Senonian.	1. Soft Chalk without flints.	*Belemnites mucronatus*, many sponges above; few sponges below.	Zone of *Marsupites* 320
		2. Chalk with imperfect flints.	Zone of *Micraster*	120
		3. Chalk with tabular flints.	Barren Zone	50
Lower Chalk.	Turonian.	Slaty Chalk with thin flints. 4. Creamy Chalk with nodular flints.	Zone of *Inoceramus mytiloides*	200
	Cenomanian.	5. Grey Chalk without flints.	Zone of *Holaster subglobosus*. Zone of *Belemnites minimus*.	100
Gault.	Albian.	6. Red Chalk.		

Professor Phillips, in his short account of the Yorkshire Chalk, prepared the following section of the Cretaceous and subjacent series in Yorkshire. This explains his views, and may be compared with the section by Mr. Blake :—

Upper Chalk	Rich in Spongidæ, Marsupites, &c.,	100 feet.
Middle Chalk, with flints	Few fossils	400 „
Lower Chalk	Few fossils	100 „
Red and Grey Chalk	Many fossils, *Belemnites Listeri*	50 „
Specton clay	Fossils abundant, *Hamites*, *Exogyra*	200 „
Portland band		5 „
Kimmeridge clay	Fossils abundant, *Am. biplex*, *Ostrea deltoidea*	300 „
	The Corallian series below.	

Possibly the Red Chalk may represent the *Upper Greensand* in part, but as physically occurring in the south of England, neither this nor the Lower Greensand is known in Yorkshire. The Lower Greensand of Kent, Surrey, and Hampshire is the Upper Neocomian of Speeton, which, in addition, possesses the Middle and Lower Neocomian of Germany, or the northern type.

On a general view, the whole series of deposits below the Red Chalk and above the Coralline Oolite of this area must be regarded as a peculiar group of argillaceous sediments, in a geographical area or marine basin, removed from those littoral agencies to which the Greensands and their accompanying conglomerates and sandbanks were exposed in the south of England. The Speeton, Kimmeridge, and Portlandian beds are all argillaceous, and lithologically so similar that, but for their respective faunas, they could scarcely be separated.

Physical Aspect.—The Wolds of Yorkshire form one of the most remarkable features in the county. High and bare of trees, yet not sterile or dreary, they are, like all Chalk downs, waterless and smooth, winding, ramifying valleys. The extent of surface occupied by the

Chalk formation of the Wolds is about 380 square miles, and the thickness not less than 600 feet. Its fossil contents are nearly identical throughout its whole course. The structure of the Chalk of Yorkshire is much harder than that in the southern counties, and the layers of flint more generally diffused. The unconformity or overlap of the Chalk upon all the underlying strata is very marked in the geology of Yorkshire; and in no other area, except in Dorsetshire, Devonshire, and part of Wilts, is this physical feature so strongly observed. In Yorkshire the broad surface of the Chalk overlaps and spreads (to the westward) over the Kimmeridge clay, the Corallian beds, and the Lias, concealing the whole for a distance of from 12 to 20 miles.[1] The Chalk has been perforated by wells and pits, and found to rest upon Kimmeridge clay near Sherburn, and on Upper Lias (in a deep well) at Huggate, clearly showing the unconformity under the central part of the Wolds. There is every probability that the Chalk once extended much further to the west and to the north than is shown by its present escarpment-line. The close of the Jurassic period witnessed extensive denudation, followed by great depression, the deep-water accumulations of the Cretaceous sea, with its Echinodermal, Sponge, and other Protozoan fauna, covering up the wasted or denuded older and underlying strata.

Fauna.—Although the fossils which (from their wide geographical, but limited geological, range) are chosen to represent the succession of life, are found in the North in the same order of time as in the South of England, there are yet many others more local, by which the Southern Upper Cretaceous series are known, but which are absent in the Yorkshire Chalk, thus apparently indicating deposition in a somewhat separated area or basin. The almost total absence, with one exception, of Gasteropoda, also of predaceous or carnivorous Fish (Placoidei), so common in the Chalk of Kent and Sussex, is significant. The Cephalopoda also are scarcely represented. No *Turrilites* or *Scaphites* are known in Yorkshire to occur in the Lower beds, where they are so plentiful and characteristic in the Southern Chalk. Again the absence of *Crustacea*, *Teleostian Fishes*, and *Reptilia* is remarkable, and shows a closer agreement with the fauna of the Chalk of North-West Germany (which has been well described by F. Römer and others), than with the fauna of our southern counties, whose affinity is rather with Northern France or the area comprised in the Anglo-French basin.

The following species occur in the several Zones named:—

[1] See Ramsay's or Greenough's map of England, where this feature explains itself, so far as the surface is concerned. The supposed anticlinals (which range from the Vale of York, probably from York to Speeton or Filey Bay, and from Allerthorpe through the Huggate area towards Flamborough Head), although hidden, do with little doubt exist. The re-entering curves of the Oolites and Lias depend upon a deeply-seated, broad, and gentle anticlinal line of elevation. The apex of this anticlinal was truncated and extensively denuded of the Lias and Oolites, and the Chalk deposited over the denuded floor, thus overlapping the older strata, to the west. The alluvial and drift beds of Holderness equally cover up the eastern portion of the Chalk, until again exposed on the Norfolk coast.

TABLE XCIII.—*Fauna of the Yorkshire Chalk-Zones.*

Zone 1. (Zone of *Belemnites mucronatus*), *Ptychodus latissimus, Nautilus lævigatus, Scaphites binodosus, S. inflatus* and *S. compressus, Hamites cylindricus, Belemnitella quadrata, Avicula tenuicostata, Ananchytes pilula, Marsupites ornatus, M. lævigatus.* and *Plocoscyphia.*

Zone 2. (Zone of *Micraster*), *Ammo. Lewisiensis, Pleurotomaria perspectiva, Spondylus latus, Cellepora, Alecto, Siphoniotyphlus plumatus, Cidaris subvesiculosa, Cyphosoma,* sp., *Inoceramus Brongniarti, I. involutus, I. digitatus, I. lingua, Anomia, Terebratula carnea, Rhynchonella Mantelliana, Cardiaster excentricus, C. rostratus, Ananchytes ovatus, Micraster cor-anguinum, M. cortestudinarium, Parasmilia centralis, Plocoscyphia, Ventriculites,* and *Scyphia pedunculata.*

Zone 3. (*Barren Zone*), *Inoceramus Cuvieri, I. Brongniarti, Terebratula semiglobosa,* and *Ananchytes ovatus.*

Zone 4. (Zone of *Inoceramus mytiloides*), *Ptychodus mammillaris, Spondylus fimbriatus, Salenia granulosa, Inoceramus Cuvieri, I. mytiloides, Terebratula semiglobosa, T. gracilis, Rhynchonella Cuvieri, Echinoconus subrotundus,* and *Ventriculites simplex.*

Zone 5. (Zone of *Holaster subglobosus*), *Nautilus Bouchardianus, Ammo. peramplus, Avicula gryphæoides, Kingena lima, Actinopora calyx, Pseudodiadema ornatum, Holaster subglobosus, Terebratula semiglobosa, Rhynchonella lineolata, Cardiaster rostratus,* and *Discoidea cylindrica.*

Zone 6. (Red Chalk), Zone of *Belemnites minimus, Nautilus Bouchardianus, Ammo. peramplus, Belemnites minimus, Plicatula pectinoides, Avicula gryphæoides, Kingena lima, Cidaris gaultina, Holaster suborbicularis, Inoceramus sulcatus, I. tenuis, Terebratula biplicata, T. semiglobosa, T. capillata, Rhynchonella Wiestii, R. latissima,* and *Bourgueticrinus rugosus.*

As regards the flints in the Yorkshire Chalk, they are not so anomalous as is usually believed, but show the same varieties as elsewhere.[1] Different portions have different developments in the various localities, sometimes causing either the Upper or Lower Chalk to be almost overlooked, so that the Middle Chalk ought to be called the "Chalk with flints."

Chalk of Scotland.

Professor Judd[2] has shown that the Cretaceous strata of the same type in the Western Highlands have been preserved under the great lava or volcanic plateaux of Mull and Morvern.

The Upper Cretaceous strata of the Western Highlands everywhere rest upon the older rocks.

a. At Carsaig, they repose directly upon the Middle Lias.

b. At Loch Aline, they overlap successively the Lower Lias, the Infra Lias, and the Poikilitic strata.

c. At Gribun they lie in part upon Poikilitic strata and in part on old Gneissic rocks, probably Silurian.

[1] Mr. Blake with others would, on lithological grounds, divide the Chalk throughout England into 3 portions:—

1st. *A Lower Chalk*, absolutely flintless below, and sparingly flinty towards the top, the amount varying in different localities.

2d. *A Middle Chalk*, characterised by the abundance of tabular flints or flint nodules, in regular lines.

3d. *An Upper Chalk*, almost and sometimes quite flintless at the base, and becoming absolutely so towards the top.—(Blake, *loc. cit.*, p. 264.)

[2] Q. Jour. Geol. Soc., vol. xxxiv., "On the Secondary Rocks of Scotland."

Nearly 200 feet of strata occur in four subdivisions, viz. :—

Chalk.	1. White marly and sandy Chalk with seams of lignite	20 feet.
	2. White Chalk (silicified) with flints, *Belemnitella mucronata*	10 „
	3. Thick white sandstones with carbonaceous matter	100 „
Upper Greensand.	4. Glauconite sands and shelly Limestone, with *Exogyra conica*, *E. haliotoidea*, *Nautilus Deslongchampsianus*, *Perten asper*, *Janira quinquecostatus*, and *Spongia paradoxa*	60 „
		190 „

No Ammonites seem to occur in the Scottish deposits.

At pp. 734–6 (*loc. cit.*), Mr. Judd tabulates 7 divisions from the east end of Beinn-y-Hattan, Morvern.

CHAPTER XLIX.

CRETACEOUS ROCKS OF IRELAND AND THE CONTINENT.

Cretaceous Strata of Ireland.

THE Cretaceous Rocks of Ireland have a very limited range and small vertical thickness, occurring only in one small area in the north-east.

The formations present are the so-called "*Hibernian Greensand*," divided into 4 Zones, and the *Upper Chalk*, also divisible into 4 Zones; the French "Middle Chalk"—Turonien and Sénonien[1]—being absent, as well as the Lower Chalk proper of England, or the Turonien. [See Table of Equivalents.]

The Hibernian Sandstone of Professor Tate[2] embraces the Upper Greensand, Chalk Marl, and Lower Chalk of England, and the two groups of *Pecten asper* and *Ammonites navicularis* of France; which are again subdivided into 6 Zones, 4 of which illustrate the former group (*P. asper*), viz. :—

4. The Zone of *Turrilites costatus*.
3. The Zone of *Pygurus lampas*.
2. The Zone of *Turrilites costatus*.
1. The Zone of *Ostrea vesiculosa*.

The second group of *Ammo. navicularis* contains the 2 Zones—

2. *Ostrea biauriculata*, and
1. *Rhynchonella compressa*.

The Hibernian series forms *three* Lithological Zones, each with its own suite of fossils, and may be studied in most of the glens of the

[1] According to MM. Hébert and Triger.

[2] This name was proposed by Mr. Tate for the Cretaceous beds underlying the Upper Chalk of Ireland, the term "Upper Greensand," as used in England, not being sufficiently comprehensive, since the Irish strata may more perfectly be correlated with the "Étage cénomanien" of D'Orbigny. The Gault has no representative in Ireland.

Antrim Hills. Professor Tate has selected as a type section those beds exposed in "the Woodburn stream, by the well-known Priest's Hole, and on Carrickfergus Common." These beds occupy an isolated area in the north-east of Ireland, and are also the most north-westerly Cretaceous deposits in Europe.[1]

Hibernian Greensand.

a. **Glauconite Sands.**—Composed of dark-green Glauconitic and arenaceous grains in an argillaceous paste; it is the most persistent of the divisions, and uniformly about 8 feet thick. The fossils are confined to the bed of *Exogyra conica* (Zone). Thirty-six species are recorded from this Zone, and mostly confined. This is the "Glauconous Sand" of Portlock.[2] The following are some of the more important species, placed according to their value:—"*Exogyra conica*, var. *lævigata*, *Pecten orbicularis*, *P. Dutemplei*, *Avicula lineata*, *Pecten quinquecostatus*, *Arca carinata*, *Belemnites ultimus*, *Am. varians*, *Pecten virgatus*, *Ditrupa deformis*."

b. **The Grey Marls, Yellow Sandstones, and Chert.**—The characteristic fossils of these sandstones of Colin Glen, Black Mountain, &c., are *Ostrea carinata*, *Pecten æquicostatus*, *P. quadricostatus*, *Rhynchonella latissima*, and *Vermicularia quinquecarinata*, *Ditrupa deformis*, *Discoidea subuculus*, and *Micrabacia coronula*. The known fauna of these marls, &c., is 20 species, the *Asiphonida* predominating. (*Vide* Table *loc. cit.*)

c. **The Chloritic Sands and Sandstones.**—"This division includes part of the 'Mulatto' of the workmen, and part of the Chloritic Chalk of Col. Portlock."[3] The fossils of this series are chiefly derived from the band characterised by *Inoceramus crispi*. No less than 76 species occur, the chief of which are *Inoceramus crispi*, *Ostrea semiplana*, *O. canaliculata*, *Terebratula obesa*, *T. carnea*, *Rhynchonella robusta*, *R. latissima*, *Pecten quinquecostatus*, *Spondylus spinosus*, *Catopygus carinatus*, *Cidaris vesiculosa*, and *Epiaster distinctus*.

Upper Chalk.

a. **Chloritic Chalk**, or **Basement Bed of the White Limestone.**—"This division is essentially a local development. Its fossil contents are chiefly *sponges* and *Ananchytes ovatus*; the former characterise a distinct Palæontological Zone reposing upon that of *Ananchytes*," with *Ananchytes ovatas* (type), *A. gibbus*, and *Ga'erites albogalerus*.

In the Spongarian Zone the characteristic forms are *Camerospongia fungiformis*, *Ventriculites alternans*, *V. decurrens*, and *Etheridgia mirabilis*.

b. **White Limestone or Hard Chalk.**—An imperfectly bedded compact limestone. It is overlain along the Antrim coast and inland by the great Basaltic flow, and rests either upon the Chloritic chalk or the Hibernian greensand, or (at Kilcorig near Lisburn) on the new red marls. Contact with the Basalt shows abundant evidences of induration and metamorphic change—so much so, that the chalk is converted into compact, hard, white limestone, and even in places into crystalline marble. The limestone is everywhere capped by a layer of altered chalk flint, imbedded in an ochreous clay, which fills up the hollows or pipes of

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[1] "The most northerly points on the globe where chalk deposits are known are in the vicinity of Thistedt in Jutland (57°), and at Aberdeen, while the last appears in the south coast of the island of Rathlin, off the north coast of Co. Antrim. The most westerly points in Ireland where the chalk is found *in situ* are Benyevenagh and near Dungiven, Co. Londonderry, long. 6° 55′."

[2] *Vide* Tate, Q. J. Geol. Soc., vol. xxi. pp. 28–32, for every species occurring in these "Hibernian beds," arranged in tabular form.

[3] Geol. Report of Londonderry.

the denuded chalk. "The White Limestone bears evidence of great denudation, as proved by two conditions: first, in its variable thickness, attaining a maximum of about 100 feet, and dwindling down to a few feet in Colin Glen and Woodburn River; second, in the Flint Gravel-bed which is interposed between it and the Basalt, and which is a constantly accompanying feature throughout the district."

The fauna of the White Limestone comprises 83 species, but individually these are not plentiful. The characteristic forms are *Ammonites gollevillensis*, *Belemnitella mucronata*, *Turritella unicarinata*, *Cinulia catenata*, *Ostrea vesicularis*, *Pholadomya cordata*, *P. Stewarti*, *Pecten nitidus*, *Terebratula carnea*, *Rhynchonella octoplicata*, *Megerlia lima*, *Ananchytes ovatus*, type and var. *A. pyramidatus*, *Cardiaster ananchytes*, *Galerites abbreviatus*, *Cyphosoma corollare*, *Parasmilia centralis*, *Guettardia stellata*, and *Paramoudra Bucklandi*.

The contents of the columns headed in the Table "Upper Chalk, White Limestone,"[1] not only clearly indicate that the White Limestone is of Upper Chalk age, but point to its representing a high stage in that formation, suggesting its parallelism with the Norwich chalk, as Professor Tate has shown.[2]

The Cretaceous beds of Ireland are divided into the following lithological Zones, but these do not agree or accord with the palæontological horizons:—

1. "White Limestones" with flints.
2. Chloritic Sandstones and Sands, "Mulatto stone."
3. Yellow Sandstones and Marls.
4. Glauconite Sands.[3]

[1] Tate, Q. Jour. Geol. Soc., vol. xxi. pp. 28–32.

[2] Prof. Edw. Forbes believed it extremely probable that the Chalk of Antrim, in its greatest part, was equivalent to the English Upper or Norwich Chalk, and also the equivalent of the Maestricht or Yellow Chalk of Belgium.

[3] For bibliography and history of the Irish Cretaceous Series, *vide* R. Tate, "On the Cretaceous Rocks of Ireland," Q. Jour. Geol. Soc., vol. xxi.

TABLE XCIV.—*Distribution of the Chalk of France, England, and Ireland.*

Formations.	France.		England.	Ireland.	
Maestrichtien.	Craie Supérieure.	Zones of	Upper Part of Norwich Chalk.		Upper Part of White Limestone.
Sénonien . .	Craie blanche ou Craie à *Belemnitella mucronata.*	*Belemnitella mucronata.*	Upper Chalk.	Upper Chalk.	White Limestone. *Rhynchonella octoplicata, Terebratula carnea, Ananchytes ovatus, Belemnitella mucronata, Holaster pilula.*
		Belemnitella quadrata.			Spongarian Zone. *Ventriculites radiatus, Etheridgia mirabilis, Cephalites.*
					Zone of *Ananchytes gibbus, Echinoconus conicus.*
	Craie Marneuse ou Craie à *Spondylus spinosus.*	*Micraster coranguinum.*			
		Micraster cortestudinarium.			
		Inoceramus labiatus.			
Turonien . .	Group of *Inoceramus problematicus.*	*Ammonites peramplus.*	Lower Chalk.	Absent.	
		Rhynchonella Cuvieri.			
		Terebratula carontonensis.			

Cénomanien	Group of *Ammonites navicularis.*	*Ostrea biauriculata.*	(Without fossils.)	Hibernian Greensand.	Zone of *Exogyra columba.* — *Inoceramus striatus, Corax falcatus, Trigonia Dædalea, Ammo. Lewesiensis, Ptychodus mammillaris, Anatina Royana, Exogyra laciniata.*
		Rhynchonella compressa.	Lower Chalk.		
	Group of *Pecten asper.*	*Turrilites costatus.*	Chalk Marl.		Zone of *Inoceramus crispi.* — *Pleurotomaria perspectiva, Ostrea flabelliformis, O. canaliculata, Catopygus columbarius, Orbitolina concava, Cidaris vesiculosa.*
		Pygurus lampas.	Upper Greensand.		
		Turrilites tuberculatus.			Zone of *Ostrea carinata.* — *Exogyra haliotoidea, Pecten æquicostatus, Ditrupa deformis, Micraster distinctus, Discoidea subuculus, Micrabacia coronula.*
		Ostrea vesiculosa.			Zone of *Exogyra conica.* — *Pecten asper, P. quinquecostatus, P. Dutemplei, Myacites mandibula, Ammo. varians.*
Albien			Gault.	Absent.	

(R. TATE, *loc. cit.*, pp. 34-35.)

Cretaceous Rocks of France and Belgium.

"The Cretaceous system, so extensively developed in Western Europe, is distributed in large basins, which, on the whole, correspond with those of the chief rivers. Thus in France there are—

"The basins of the Seine or of Paris.
" " Loire or of Touraine.
" " Rhone or of Provence.
" " Garonne or of Aquitania.
Including all the area up to the slopes of the Pyrenees.

"In most cases these areas present such lithological and palæontological differences in their Cretaceous rocks, as to indicate that they may have been in Cretaceous times distinct basins of deposit."—(Geikie.)

NEOCOMIAN.—"Both in the Paris basin and in the southern provinces a threefold division of this series has been traced":—

1. *The Lowest Group*, in Marne, Haute Marne, Meuse, &c., consists of sands, marls, *Spatangus-limestone*, with *Spatangus*, *Toxaster complanatus*, *Perna Mulleti*, and clays, with *Ostrea Leymeriei*.

2. *The Middle Group*, or "Urgonien of D'Orb., consists of fresh-water shells, sands, and ironstones in the northern area; but in the south expands into massive limestones, with *Chama* (*Caprotina*) *Anomia*, *Requienia* (*Diceras*) *Lonsdalei*, *Pterocera pelagi*, *Panopæa irregularis*, and *Terebratula sella*."

3. *The Upper Group*, or Aptien of D'Orb., is composed in the Paris basin of *Plicatula clays—Plicatula placunea*, *Exogyra sinuata*, *Ancyloceras matheronianum*, *Am. fissicostatus*, &c.

"On the north coast of France the Folkestone type of Neocomian beds is well seen between Boulogne and Calais."

Gault or Albian[1] "appears on the French coast opposite to Folkestone, the lithological and palæontological features being the same as on the English side of the Channel. The dark pyritous clays sweep round the northern and eastern margin of the great Paris basin, and appear on the west near Havre." The following is their subdivision in descending order:—

3. *Zone of Ammonites inflatus* (*rostratus*).—"Glauconite clay of Saucerre, &c. At Wissant it has yielded 140 species, nearly all the same as those in England; among them are—*Ammo. inflatus*, *A. splendens*, *A. auritus*, *Nautilus radiatus*, *Hamites intermedius*, *Natica gaultina*, *Rostellaria carinata*, *Inoceramus sulcatus*, *Perna Rauliniana*, *Janira quinquecostata*, *Plicatula pectinoides*, and *Kingena lima*."

2. *Zone of "Am. interruptus.—A. splendens*, *A. lautus*, *A. denarius*, *Hamites rotundus*, *Inoceramus sulcatus*, *Plicatula pectinoides*," &c.

1. *Zone of Ammo. mammillaris.*—"Greensand, containing phosphatic nodules, *Ammo. mammillaris*, *A. Raulinianus*, *A. Beudanti*, *Natica gaultina*, *Pterocera bicarinata*, *Inoceramus Salomoni*, and *Rhynchonella Gibbsiana*," &c.—(Hébert).

Cenomanian (Craie Glauconieuse).—M. Hébert divides this formation into two groups—

I. The Lower or Rouen Chalk, equivalent to the Upper Greensand

[1] Consult Barrois: Bull. Soc. Géol. de France, 2d sér., iii. 707; also Renevier, *ib.*, 2d sér., vol. iii.

	a. Zone with *Holaster sub-orbicularis.*			Aix.	*cava*, of Cassis and Escragnolles, &c. &c.

Lower Cretaceous Period.

3. Gault.			Wanting.	Wanting.
			Basin of Paris.	Southern France, Switzerland, &c. &c.
2. Neocomian Formation.	Sub-Formation (sous-étage), Aptien of D'Orbigny.		Clay with *Plicatulæ* and *Ostrea aquila* (Argiles à Plicatules).	Aptien Marls—1st stage of M. D'Archiac. Sandstones with *Ostrea aquila* of the Perte-du-Rhône (Upper Aptien of Pictet and Campiche, 1858). Limestone with *Ostrea aquila* of the Pyrenees.
	Middle Subdivision. Urgonien of D'Orbigny.	Upper Stage.	Red Bed of Vassy.	Limestones and Marls with *Orbitolites.* Rhodanien Stage of Renevier. Lower Aptien of Pictet and Campiche.
		Lower Stage.	Fresh-water Sandstones, Sands, and Marbled Clays.	Limestone with *Dicérates* of Elie de Beaumont and Dufresnoy. Limestone with *Chama* (*Caprotina ammonia*), Urgonien Stage of Renevier, Pictet, &c.
	Lower Subdivision.	Upper Stage.	Oyster Clays (Argiles ostréennes).	Limestone with *Scaphites Yvanii* of Barrême, &c.
		Middle Stage.	Limestone with *Spatangus.*	Limestone with *Spatangus.* Limestones and Clays with *Belemnites dilatatus*, &c.
		Lower Stage.	Marls and Sands.	Limestone *Ammonites macilentus.* Diphya Kalk of the Porte-de-France, of the Tyrol, the Carpathes, &c.
1. Wealden Stage.				

[*To face p.* 575, *Vol. II.*

and Grey Chalk of England in the Northern region of France and Belgium; it is subdivided into Lower, Middle, and Upper groups.

II. Upper or marine sandstone, wanting in England, France, and Belgium (Hébert.)

Turonian (Craie Marneuse).—The facies of the Turonian series varies geographically; according to Hébert only the lower part occurs in the Northern basin. Hébert places the Zone of *Holaster planus* at the base of the Sénonian groups. Dr. Barrois, however, regards the Zone of *Holaster planus* as being at the top of the Turonian series.

Senonian.—The *Micraster* and *Belemnitella* groups are fully developed in the Northern basin. The Senonian embraces the true or Upper White Chalk under two divisions—

1. The *Micraster* group.
2. The *Belemnitella* group.

1. *Micraster group.*—White Chalk, in the *lower part* of which occurs *Micraster cor-testudinarium*, and in *the upper*, *Micraster cor-anguinum.*
2. *Belemnitella group*, with *Belemnitella quadrata* in the *lower Zone*, and *B. mucronata* in the *upper* (or Meudon Chalk).[1]

Danian.—This Zone does not appear to have been developed in England, and only in the Northern basin in France. It is the Craie supérieure de Faxoe, de Scanie, et de Ciply (Belgique), and the well-known Chalk of Maestricht is equivalent to part of the Danian series. The highest chalk-beds in England occur in Norfolk, but the Belgian or higher Maestricht Chalk proper or its species have not been detected. In the South-East of Belgium the Danian series is well exposed. A few of the higher chalk or Danian species occur in Britain. Amongst them *Belemnitella mucronata*, *Inoceramus Cuvieri*, *Ostrea flabelliformis*, *O. vesicularis*, *Crania ignabergensis*, *Terebratulina striata*, and *Ananchytes ovatus*, &c.[2]

The above description is based mainly on the classification of M. Hébert, further illustrated by Table XCV.

System of M. Coquand.

M. Coquand has long devoted his attention to the Cretaceous systems generally, and especially to those so largely developed in the south of France. The following descriptive Table, illustrating the different systems and European divisions, has been prepared by him.

M. Coquand divides the Cretaceous system into 17 stages, 9 of which occur in Britain.

To our White Chalk he applies the name "*Campanien*," while to the upper portion only of our Lower Chalk the term "*Santonien*" is

[1] The same general palæontological facies occurs in these as in corresponding strata in England, the species as a whole being the same. In the South and South-East of France, the corresponding series are partly marine and partly fresh-water, and contain deposits of lignite.

[2] Consult Dumont: Mém. Terrains Crétacés et Tertiaires, &c., 1878–9. Brux. elles; also M. Mourlon: Géologie de la Belgique, Tome 1, 1880.

given. Four divisions then intervene in France between the upper and lower portion of our Lower Chalk, to which last the term *Ligérien* is applied. This is followed by Coquand's *Étage Carentonien*, which comprises our Chalk marl.

Then succeed his *Étages Gardonien* and *Rothomagien*, followed by the "*Étage Vraconien*" or Cambridge Coprolite beds (Cambridge Greensand). Immediately below the *Vraconien* is the true Gault (of Folkestone and Wissant), or *Étage Albien* of the French. In the *Étage Urgo-Aptien* he places the Lower Greensand, the *Aptien*, and a portion of the Neocomian of Judd, while the true *Neocomien* would comprise the "Lower Neocomian" of Judd.

The following is Coquand's detailed scheme, with both British and foreign equivalents and characteristic fossils :—

TABLE XCVI.—*Foreign Equivalents of British Cretaceous System, as Classified by M. Coquand.*

I. Upper Cretaceous.

Upper Cretaceous.

1. Garumnien (Leymerie), named after the Department of the Garonne. The beds are of fresh-water origin in Provence, and fluvio-marine in the Pyrenees. This comprises D'Orbigny's Pisolitic stage. It does not occur in Britain. *Sphærulites Leymerici* and *Cyrena garumnica* characterise this stage.
2. Dordonien (Coquand), after the Department of Dordogne. This includes the Upper Maestricht beds, which contain the same Rudistes as the Dordogne. *Hippurites radiosus, Radiolites Jouanneti, Sphærulites ingens,* and *Ostrea Villei* are characteristic.
3. Campanien (Coquand), from the country of Champaign. This corresponds to the Sénonien of D'Orb. It is the White Chalk of England, the Obere Kreide of the Germans, and the Craie Blanche de Meudon of the French. *Ostrea vesicularis, Belemnitella mucronata, Terebratula carnea, Ananchytes ovatus, Hemipneustes radiatus,* and *Baculites Faujasii* are the typical forms.
4. Santonien (Coquand), from Saintonge. Corresponds to the Sénonien of D'Orbigny, to the upper portion only of the Lower Chalk, to the Craie Marneuse and Craie de Villedieu, and to the Oberer-Pläner of the Germans. *Micraster cor-anguinum, Belemnitella quadrata, Spondylus truncatus, Rhynchonella vespertilia, Ostrea frons,* and *Radiolites fissicostatus* are prominent species.
5. Coniacien (Coquand), from Cognac, corresponds to the base or lower portion of the Sénonien of D'Orbigny, to the Sables d'Aix-la-Chapelle (base). Does not occur in England.

II. Middle Cretaceous.

Middle Cretaceous.

1. Provencien (Coquand), after Provence. Corresponds to the Turonien of D'Orbigny.	*Hippurites cornu-vaccinum, Sphærulites angeiodes,* and *Caprina coquandi.*
2. Mornasien (Coquand), after Mornas Vaucluse. Comprises the celebrated Grès d'Uchaux (Turonien of D'Orbigny). Wanting in England.	*Ammonites requieni, A. Matheroni.*
3. Angoumien (Coquand), after Angoulême. Wanting in England, but corresponds to the Turonien of France, D'Orbigny.	*Radiolites cornu-pastoris, R. lumbricalis, Hippurites requieni.*

TABLE XCVI.—(*Continued.*)

MIDDLE CRETACEOUS (*continued*).	4. LIGERIEN (Coquand), after the Loire. Corresponds to the lower part of the Lower Chalk of England, to the base of the Craie Marneuse, to the Craie Tuffeau, to the Turonien of D'Orbigny, the Mittler-Quader-mergel, Plänerkalk of the Germans.	*Inoceramus problematicus, Ammonites Fleurianus, A. papalis, Terebratula carentonensis.*
	5. CARENTONIEN (Coquand), after Charente. Corresponds to the Chalk Marl of England, to the Cénomanien of D'Orbigny, the Sables du Mans, the Unterer-Pläner of the Germans.	*Caprina adversa, Sphærulites foliaceus, Ostrea biauriculata, O. columba, O. flabellata,* and *Terebratula phaseolina.*
	6. GARDONIEN (Coquand), after the Gard. This stage is lacustrine in origin.	*Vicarya Renauxiana, Teredo fleuriansi.*
	7. ROTHOMAGIEN (Coquand), after Rouen. Corresponds to the Chalk Marl and Lowest Chalk of England, to the Craie Chloritée or Glauconieuse, to the Cénomanien of D'Orbigny, the Unterer-Pläner Inférieur (Greensand of Essen).	*Ammo. Rhothomagensis, A. varians, A. falcatus, Scaphites æqualis, Radiolites Mortoni, Turrilites costatus, Pecten asper, Terebratula pectita, T. lyra,* and *Ostrea conica.*
	8. VRACONIEN (Renevier), Vraconne in Switzerland. Corresponds to the Gault Supérieur of the Swiss, the Upper Gault of Cambridge or Cambridge Greensand, the Flammenmergel of the Germans.	*Ammonites inflatus, Rhynchonella sulcata, Am. auritus, Am. latidorsatus.*
	9. ALBIEN (D'Orbigny). Corresponds to the true Gault of Folkstone and Wissant, and to the Oberer and Mittler Gault of the Germans.	*Ammonites splendens, A. mammillaris,* and *A. Raulini.*
	III. LOWER CRETACEOUS.	
LOWER CRETACEOUS.	I. URGO-APTIEN—	
	1. Argiles à plicatules—(the Lower Greensand of the English geologists) Aptien of D'Orbigny, Unterer-Gault-Mergel, and U.-G.-Thon of the Germans.	*Ammonites nisus, Am. gargasensis, Belemnites semicanaliculatus, Ostrea æquila, Terebratella astieriana, Plicatula placunea.*
	2. Couches à Orbitolites (Étage Rhodanien of Renevier).	*Ancyloceras Matheronianum, Ammo. fissicostatus, Nautilus plicatus, Plicatula placunea, Pseudodiadema malbosi, Caprotina Lonsdalii, Ostrea aquila, O. macroptera, Orbitulites lenticularis.*
	3. (*a*) Urgonien (D'Orbigny.	*Requienia Lonsdalii, R. ammonia, Nerinæa coquandi, N. gigantea, Heteraster oblongus, Ostrea aquila, Nautilus plicatus, Scaphites Tranii, Orbitulites lenticularis.*
	(*b*) Barrémien (Coquand).	*Ancyloceras Duvalii, A. Emerici, A. Tabarelli, Ostrea Leymerici,* and *Terebratella Astieriana.*

TABLE XCVI.—(*Continued.*)

Lower Cretaceous.	*a* and *b* are parallel—(*a*) represents the Coral aspect, (*b*) the Littoral aspect. These three subdivisions correspond with the Upper and Middle Neocomian of Mr. Judd (England), and the Néocomien Supérieur of Cornuel.	
	II. Néocomien includes the Marnes d'Hauterive, Lower Neocomian of Judd, Hils-Thon of the Germans.	*Ammonites astierianus, A. multiplicatus, Ostrea Couloni, O. rectangularis, Belemnites latus,* and *B. dilatatus.*
	II. Valengien, the equivalent of the Wealden of England and of the first stage of the Néocomien Inférieur of Cornuel.	*Ammo. Gervilianus, Strombus Sautieri, Pygurus rostratus.*

TABLE XCVII.—*Subdivisions of the Cretaceous System in France and Belgium (by M. Renevier).*

Super-Cretaceous Group or Sénonien.	Danien = Upper Chalk of Maestricht; Limestone with *Baculites* (Pisolitic Limestone; occurs neither in England nor Switzerland). Sénonien = White Chalk; Chalk with Flints; Chalk of Meudon; Upper Chalk, Norwich, Gravesend, Woolwich in England, Seewenkalk in Switzerland. Santonien = Lower Sénonien, Chalk of Villedieu [peculiar to France; does not occur either in Switzerland or Great Britain].
Méso-Cretaceous or Cénomanien.	Turonien = Craie tuffeau, Chalk with *Inoceramus mytiloides;* Upper portion of Lower Chalk of Beachy Head in England; does not occur in Switzerland. Carentonien = Upper portion of the Greensands of the Sarthe [Zone with *Ostrea biauriculata;* does not occur either in England or Switzerland.] Rothomagien = Craie Marneuse, Chalk of Rouen, Lower part of the Chalk of Ventnor and Sussex; Chloritic Marl of England, Cheville and St. Croix in Switzerland. Vraconnien = Upper Greensand. Zone with *Pecten asper;* Upper Gault in Switzerland, Cheville, St. Croix, Perte du Rhône; Warminster and Cambridge in England. Albien = Gault, Middle and Lower Gault in Switzerland; Cheville, Perte du Rhône, St. Croix, &c. Folkestone, Wellant, &c. &c.
Infer-Cretaceous or Néocomien.	Aptien = Clay with *Plicatulæ*, Upper Aptien; Hard Sandstone of the Perte du Rhône. Upper part of the Lower Greensand of England. Rhodanien = Lower Aptien; Yellow Marls of the Perte du Rhône; red bed of Vassy; Lower portion of the Lower Greensand of England; Perna beds of the Crackers (Isle of Wight), *Diceras Lonsdalii.* Urgonien = Upper Neocomien; white Limestone with *Requienia Ammonia.* 1. Zone of *Rudistes;* Yellow Limestone of Neuchatel, Mortean Marl of Hauterive. Yellow Marl with *Am. Astierianus.* Valangien = Lower Neocomien. Zone with *Pygurus rostratus.* Limestone of Berrias?

Cretaceous Rocks of Germany and Northern Europe.

The extensive and varied deposits embraced in the Cretaceous series of Germany, Denmark, and Sweden, were accumulated in the same basin, province, or contained area as that of Britain, the N. of France, and Belgium, the same palæontological succession being traceable through the whole sedimentation.[1]

The *Cenomanian*, *Turonian* and *Senonian* rocks of Germany present great anomalies with those of France and England. Lithogically the contrast is greater than palæontologically, the organic remains showing that they belong to the same period and marine area of deposit.

Switzerland.—The "Neocomian" groups are so well and characteristically developed in Switzerland as to have received from thence their collective name. They are thickly developed in the Neufchatel area, but in the Jura region they seldom exceed 150 feet. *Toxaster complanatus*, *Rhynchonella depressa*, &c., characterise the blue marls (Marnes de Hauterive).

The Neocomian formation in the Alpine region is represented by a great thickness of marls and limestones, which are conspicuously shown in the range of mountains separating Berne from Vallis. *Hippurites* (*Caprotina*) and *Radiolites* abound in the Limestones. The Gault with its rich fauna (Perte du Rhône, St. Croix) is "traceable in the Swiss Jura and the Alps of Savoy."[2]

In the North-Eastern Alps occur the variable, rich, and locally-developed groups of the Gossau beds, composed of marine Marls, Sandstones, and Limestones. These rocks have yielded upwards of 500 species of fossils, only one-fourth of which occur outside that region,[3] or in another strata (Turonian). The Gosau formation corresponds in age to our Upper Greensand,[4] and contains a remarkable Vertebrate Reptilian fauna, illustrating no less than 14 genera and 18 species. Fresh-water deposits occur with *Melaniæ*, *Cyclas*, *Tanalia*, and *Unio*, &c., and land-plants representing a highly heterogenous flora, comprising *Banksia*, *Pecopteris*, *Macrozamia*, and a true palm. These fresh-water and land beds have yielded the above reptilian remains, amongst which are *Mochlodon*, *Struthiosaurus*, *Cratæoneus*, *Megalosaurus*, *Rhadinosaurus*, *Emys*, *Ornithomerus*, *Pleuropeltus*, *Crocodilus*, *Hoplosaurus*, *Doratodon*, *Oligosaurus*, *Arœosaurus*, *Ornithocheirus*.

Probably the massive hippurite-limestones of the Bavarian Alps are equivalent to the Gosau beds.

[1] For the history of the Lower Cretaceous strata of Germany (Neocomian, &c.), see Prof. Judd, Q. J. Geol. Soc., vol. xxvi.

[2] Gümbel: "Geognostische Beschreib. Bayer. Alpen," vol. i. p. 517 et seq. Von Hauer: "Die Geologie der Oesterr.-Unger. Monarchie," 1878.

[3] Consult Stoliczka, "Sitzb. Akad. Wien," xxviii.; also Gümbel, "Geognost. Beschreib. Ostbayer. Grenzgeg.," p. 700, for table of correlations of the European Cretaceous rocks with those of Bavaria.

[4] We are indebted to Prof. Suess of Vienna for great research in these Gosau deposits.

Cretaceous Rocks of India.

A vast area in Persia and Asia Minor is occupied by the hippurite limestone. "The most remarkable episode of Cretaceous time in the Indian area was the colossal outpouring of the Deccan basalts. These rocks, lying in nearly horizontal sheets, attain a vertical thickness of from 4000 to 5000 feet or more. They cover an area estimated at 200,000 square miles." These lavas were subaërial, as proved by the remains of fresh-water Mollusca, land-plants, and Insects. This is "one of the most gigantic outpourings of volcanic matter in the world." [1]

Cretaceous Rocks of North America.

The Western territories of the United States and British Columbia possess an enormous thickness of the Upper Cretaceous Rocks. Their greatest development occurs in the Western States and Territories of the Rocky Mountains, Wyoming, Utah, and Colorado, thence ranging northwards into British America, and Arctic America near the mouth of the Mackenzie River, and on into W. Greenland.

In the southern regions, over the site of Texas, the Cretaceous rocks seem to have been deposited in deeper and clearer water than elsewhere in the American region, their mass being chiefly composed of Limestone with *Hippurites* (*Caprotina* and *Caprina*) and *Orbitolites* as in Europe.

[1] Medlicott and Blanford, "Geol. of India," p. 299. Geikie, p. 831.

TABLE XCVIII.—*Showing Numerically the Distribution and Life Value of the 14 Classes occurring in the Cretaceous Rocks. No Species passes to the succeeding Tertiary Deposits.*

Classes.		No. of Genera and Species.		Low. Cretaceous.	Upper Cretaceous.				
		Genera.	Species.	Neocomian. L. G. S.	Gault.	Cenomanian. U. G. S.	Chalk Marl.	Lower Chalk.	Upper Chalk.
	Plantæ	15	28	$\frac{9}{14}$	$\frac{2}{2}$	$\frac{6}{7}$	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$
	Protozoa	87	212	$\frac{9}{15}$	$\frac{2}{2}$	$\frac{2}{10}$	$\frac{1}{1}$	$\frac{1}{10}$	$\frac{6}{11}$
	Rhizopoda	39	171	$\frac{1}{1}$	$\frac{21}{21}$	$\frac{22}{22}$	$\frac{1}{1}$	$\frac{10}{10}$	$\frac{13}{13}$
	Actinozoa	37	76	$\frac{2}{2}$	$\frac{11}{11}$	$\frac{10}{10}$	$\frac{1}{1}$	$\frac{7}{7}$	$\frac{9}{9}$
	Echinodermata	48	201	$\frac{14}{14}$	$\frac{17}{17}$	$\frac{17}{17}$	$\frac{1}{1}$	$\frac{11}{11}$	$\frac{11}{11}$
	Annelida	4	41	$\frac{3}{13}$	$\frac{2}{2}$	$\frac{3}{15}$	$\frac{1}{1}$	$\frac{2}{2}$	$\frac{4}{17}$
	Crustacea	40	110	$\frac{9}{14}$	$\frac{14}{14}$	$\frac{21}{21}$	$\frac{9}{14}$	$\frac{10}{10}$	$\frac{11}{11}$
	Polyzoa	59	114	$\frac{11}{11}$	$\frac{4}{4}$	$\frac{13}{13}$	$\frac{1}{1}$	$\frac{8}{8}$	$\frac{8}{8}$
	Brachiopoda	14	106	$\frac{10}{10}$	$\frac{8}{10}$	$\frac{10}{10}$	$\frac{10}{10}$	$\frac{10}{10}$	$\frac{10}{10}$
Pelecypoda.	Monomyaria	14	216	$\frac{12}{12}$	$\frac{13}{13}$	$\frac{13}{13}$	$\frac{9}{11}$	$\frac{7}{11}$	$\frac{8}{11}$
Pelecypoda.	Dimyaria	51	260	$\frac{39}{175}$	$\frac{24}{24}$	$\frac{39}{175}$	$\frac{6}{6}$	$\frac{12}{12}$	$\frac{7}{12}$
	Gasteropoda	66	298	$\frac{20}{77}$	$\frac{21}{21}$	$\frac{20}{100}$	$\frac{10}{10}$	$\frac{10}{10}$	$\frac{10}{10}$
	Heteropoda	1	1	...	$\frac{1}{1}$	...	...	...	...
Cephalopoda [1] $\frac{15}{175}$.	Ammonites	1	128	$\frac{1}{10}$	$\frac{1}{6}$	$\frac{1}{14}$	$\frac{1}{10}$	$\frac{1}{1}$	$\frac{1}{9}$
	Ancyloceras	1	12	$\frac{1}{2}$	$\frac{1}{2}$	...	$\frac{1}{1}$	$\frac{1}{1}$	...
	Anisoceras	1	2	...	$\frac{1}{2}$	...	$\frac{1}{1}$	...	...
	Baculites	1	4	...	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{1}$
	Crioceras	1	6	$\frac{1}{4}$	...	$\frac{1}{1}$	..	...	$\frac{1}{1}$
	Hamites	1	24	$\frac{1}{2}$	$\frac{1}{10}$	$\frac{1}{2}$	...	$\frac{1}{2}$	$\frac{1}{1}$
	Helioceras	1	4	...	$\frac{1}{1}$	...	...	...	...
	Ptychoceras	1	1	...	$\frac{1}{1}$	...	...	...	...
	Scaphites	1	5	...	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{1}$
	Turrilites	1	20	...	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{11}$	$\frac{1}{11}$	$\frac{1}{1}$
	Nautilus	1	20	$\frac{1}{11}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	Aptychus	1	6	...	...	...	...	...	...
	Belemnites	1	8	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	...
	Belemnitella	1	5	...	...	...	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{1}$
	Conoteuthis	1	1	...	$\frac{1}{1}$	...	...	...	...
	Pisces	52	111	$\frac{6}{6}$	$\frac{4}{4}$	$\frac{9}{11}$	$\frac{2}{2}$	$\frac{27}{27}$	$\frac{16}{16}$
	Reptilia	28	54	$\frac{6}{6}$	$\frac{4}{4}$	$\frac{16}{27}$	$\frac{4}{4}$	$\frac{9}{16}$	$\frac{1}{1}$
	Aves	1	2	...	$\frac{1}{2}$	...	...	...	...
		571	2247	$\frac{182}{647}$	$\frac{182}{416}$	$\frac{243}{681}$	$\frac{106}{163}$	$\frac{180}{481}$	$\frac{270}{666}$

[1] The distribution of these 15 genera is so important in the Cretaceous Rocks that they must be given in detail. Sixteen genera and 246 species range through the Cretaceous series.

TABLE XCIX.—*Organic Remains of the Cretaceous System.*

See Plates XXV., XXVI., XXVII., and XXVIII. for many characteristic species.

KINGDOM—PLANTÆ.

ALGÆ.

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Confervites	3	1	...	...	...	...	3
Chondrites	1	1	...	...	...	...	...
FILICINÆ.							
Lonchopteris	1	1	...	...	...	...	...
Caulopteris	1	...	...	1	...	...	...
LILIACEÆ.							
Dracæna	1	1	...	...	...	...	...
PANDANACEÆ.							
Kaidacarpum	1	...	...	1	...	...	...
CYCADEÆ.							
Bennettites	2	2	...	...	...	...	...
Cycadeostrobus	1	1	...	...	...	...	...
Zamiostrobus	2	...	...	2	...	...	..
Clathraria	1	...	...	1	...	...	...
Fittonia	1	...	...	...	1	1	...
Mantellia	1	1	...	...	...	...	...
Yatesia	1	1	...	...	...	...	...
CONIFERÆ.							
Pinites	8	5	2	1	...	...	...
Sequoites	3	...	2	1	...	...	...
15	28	14	4	7	1	1	3

SUB-KINGDOM—PROTOZOA.

SPONGIDA.

DIV. I.—SILICEOUS SPONGES.

MONACTINELLIDÆ.

Dirrhopalum	1	...	...	...	...	...	1
Acanthoraphis	1	...	...	1	...	...	1
Cliona	4	...	...	...	...	...	4
	6	...	...	1	...	...	6

Ord.—TETRACTINELLIDÆ.

Ophiraphidites	1	...	...	...	...	...	1
Tethyopsis	1	...	...	...	...	...	1
Stelleta	1	...	...	...	...	...	1
Geodia	4	...	...	...	...	...	4
Thenea	1	...	...	...	...	...	1
Pachystrella	2	...	...	...	...	...	2
	10	...	...	...	...	...	10

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Ord.—LITHISTIDÆ.							
Fam.—RHIZOMORINA.							
Seliscothon	2	...	...	...	...	...	2
Chenendopora	2	...	...	2	...	...	1
Verruculina	7	...	...	...	...	...	7
Stichophyma	1	...	...	...	...	...	1
Jereica	2	...	...	1	...	...	1
Scytalia	3	...	...	...	...	...	3
Stachyspongia	1	...	...	...	1	..	1
Pachinion	1	..	...	...	...	...	1
	19			3	1		17
Fam.—MEGAMORINA.							
Doryderma	4	...	...	2	...	...	2
Holodictyon	1	...	...	1	..	...	...
Pachypoterion	2	...	...	2	...	...	...
Heterostinia	1	...	...	...	...	...	1
Nematinion	1	...	...	1	...	...	...
Isoraphinia	1	...	...	...	...	...	1
	10	...	...	6	...	...	4
Fam.—ANOMOCLADINA.							
Mastosia	1	1	...	...	...	...	...
Fam.—TETRACLODINA.							
Phymatella	4	...	...	1	...	...	3
Aulaxinia	1	...	...	...	...	...	1
Callopegma	2	...	...	...	...	...	2
Trachysycon	2	...	...	2	...	...	...
Siphonia	4	...	...	3	1	...	2
Hallirhoa	4	...	...	4	...	...	...
Jerea	4	...	1	3	...	1	1
Nelumbia	1	...	...	...	...	1	1
Polyjerea	2	...	...	2	2	2	...
Bolospongia	2	...	...	...	...	...	2
Thecosiphonia	2	...	...	...	...	...	2
Turonia	1	...	...	...	...	...	1
Kalpinella	2	...	...	2	...	...	...
Thamnospongia	3	...	...	...	...	1	2
Pholidocladia	2	...	...	...	...	...	2
Ragadinia	3	...	...	...	...	...	3
Plinthosella	4	...	...	...	...	...	4
Phymaplectia	4	...	...	...	...	...	4
Rhopalospongia	2	...	...	2	...	...	...
	49		1	19	3	5	30
Order—HEXACTINELLIDÆ.							
Fam.—EURETIDÆ.							
Craticularia	2	...	...	1	...	1	2
Strephinia	2	...	...	...	...	...	2
Stauronema	2	...	...	1	...	2	...
	6			2		3	4

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.]
Fam.—COSCINOPORIDÆ.							
Leptophragma . .	2	...	...	1	...	1	2
Pleurostoma . .	1	...	...	...	...	...	1
Guettardia . .	1	...	...	...	...	1	1
Coscinopora . .	2	...	...	...	...	...	2
	6			1		2	6
Fam.—MELLITIONIDÆ.							
Aphrocallistes .	1	...	...	...	...	...	1
Fam.—VENTRICULIDÆ.							
Ventriculites . .	9	...	..	...	...	...	9
Rhizopterion . .	1	...	...	...	...	...	1
Sporadoscinia . .	2	...	...	...	...	1	1
Sestrocladia . .	1	...	...	...	...	1	...
Cœloscyphia . .	1	...	...	...	...	...	1
Polyblastidium .	2	...	...	...	...	...	2
Cephalites . .	6	...	...	...	...	...	6
	22					2	20
Fam.—STAURODERMIDÆ.							
Ophrystoma . .	2	...	...	1	...	1	...
Placotrema . .	1	...	...	...	...	..	1
Cinclíderma . .	1	...	...	...	...	...	1
Eubrochus . .	1	...	...	1	...	...	...
	5			2		1	2
Fam.—MEANDROSPONGIDÆ.							
Plocoscyphia . .	11	1	...	4	...	3	6
Tremabolites . .	1	...	...	...	...	...	1
Etheridgia . .	1	...	...	...	...	...	1
Toulminia . .	1	...	...	...	...	...	1
Camerospongia .	4	...	...	...	...	...	4
	18	1		4		3	13
Fam.—CALLODICTYONIDÆ.							
Callodictyon . .	1	...	...	...	...	...	1
Porochonia . .	1	...	...	...	...	...	1
Diplodictyon . .	1	...	...	...	...	...	1
Sclerokalia . .	1	...	...	1	...	...	1
	4			1			4
Fam.—CŒLOPTYCHIDÆ.							
Cœloptychium .	3	...	...	...	...	...	3
Sub.-Ord.—LYSSAKINA.							
Fam.—MONAKIDÆ.							
Stauractinella .	1	...	...	...	...	...	1
Fam.—POLLAKIDÆ.							
Hyalostelia . .	1	...	...	...	...	...	1

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
DIV. II.—CALCAREOUS SPONGES.							
Order—CALCISPONGIA.							
Fam.—PHARETRONES.							
Peronella	4	3	...	1	...	...	...
Tremacystia	5	3	...	...	...	...	...
Elasmocœlia	3	3	...	...	...	...	...
Corynella	3	...	...	...	...	...	...
Synopella	1	1	...	...	...	...	...
Oculospongia	1	1	...	...	...	...	...
Elasmostoma	4	...	...	2	...	...	2
Raphidonema	5	5	...	...	...	...	...
Pharetrospongia	1	...	...	1	...	...	1
Pachytilodia	1	...	...	1	...	...	...
Bonneyia	5	...	...	5	...	...	...
Talpina	3	...	...	...	...	...	3
Xanthidium	14	...	...	...	...	...	14
	—	—	—	—	—	—	—
87	50	16	1	10			20
CLASS—RHIZOPODA.							
FORAMINIFERA.							
Bulimina	10	...	4	1	5	4	7
Cristellaria	14	1	10	1	3	4	5
Dentalina	18	...	7	4	11	14	7
Flabellina	8	...	1	...	7	7	7
Frondicularia	9	...	4	...	4	5	6
Gaudriana	2	...	1	...	...	2	2
Glandulina	2	...	1	...	...	1	1
Globigerina	4	...	1	...	3	4	4
Guttulina	1	...	...	1	...	...	...
Heterostomella	1	...	...	...	...	...	1
Lagena	3	...	...	...	...	...	3
Lingulina	3	...	1	...	...	2	2
Lituola	4	...	1	1	1	1	1
Marginulina	7	...	2	...	2	5	6
Nodosaria	14	...	4	11	7	...	7
Orbitolina	2	...	...	2	...	...	...
Parkeria	1	...	...	1	...	...	...
Planulina	2	...	...	...	...	1	1
Pyrulina	1	...	...	...	...	1	...
Patellina	1	...	...	1	...	...	...
Planorbulina	4	...	3	3	3	3	3
Placopalina	2	...	...	...	...	2	...
Pleurostomella	1	...	...	...	...	1	1
Polymorphina,	5	2	...	...	...	...	5
Pullenia	2	...	...	...	...	1	1
Rhabdogonum	1	...	1	...	...	...	...
Rosalina	6	...	1	...	...	...	6
Rotalina	9	1	2	...	...	...	8
Sagrena	1	...	...	4	...	1	...
Spirillina	1	...	...	...	...	...	1
Spirolina	1	...	...	...	...	1	1
Spiroplecta	1	...	...	...	...	...	1

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Textularia	10	...	3	1	1	6	7
Trochamina	1	...	1	...	...	...	...
Tinopus	2	...	...	...	2	...	...
Truncatulina	3	...	2	2	...	1	2
Vaginulina	7	...	7	...	...	1	1
Verneuilina	5	1	2	...	...	2	3
Webbina	2	...	...	2	...	...	...
39	171	5	59	35	49	70	100
Class—ACTINOZOA.							
Actinacis	2	...	...	2	...	..	...
Astrocœnia	1	...	...	1	...	...	...
Axogaster	1	...	...	...	...	...	1
Baryhelia	1	...	...	1	...	...	...
Bathycyathus	1	...	1	...	...	...	...
Caryophyllia	4	...	1	...	...	3	3
Chisma	1	1	...	...	...	...	...
Choristopetalum	1	1	...	...	...	...	...
Cyathina	1	...	...	...	...	...	1
Cyclocyathus	1	...	1	...	...	...	...
Cyathophora	1	...	1	...	...	...	...
Cyclolites	1	...	1	...	...	...	...
Diblasus	1	...	...	...	...	1	1
Epiphaxum	1	...	...	...	...	...	1
Favia	2	...	...	2	...	...	...
Haldonia	1	...	...	1	...	...	...
Holocystis	1	1	...	...	...	...	...
Heliopora	1	...	...	1	...	...	...
Isastræa	2	1	...	1	...	...	...
Micrabacia	2	...	1	1	1	1	...
Leptocyathus	1	...	1	...	...	...	...
Onchotrochus	2	...	...	1	1	1	...
Oroseris	1	...	...	1	...	...	...
Parasmilia	7	...	...	...	...	3	7
Podoseris	2	...	2	2	...	...	...
Placosmilia	3	...	...	3	...	...	...
Peplosmilia	1	...	...	1	...	...	...
Smilotrochus	7	1	4	3	...	...	...
Spinopora	1	...	...	...	...	...	1
Stephanophyllia	3	...	...	...	1	2	2
Synhelia	1	...	...	...	...	1	...
Stelloria	3	...	...	3	...	...	...
Thamnastræa	3	...	...	3	...	...	...
Trochocyathus	3	1	3	...	...	...	...
Trochoseris	2	...	...	2	...	...	...
Turbinoseris	1	1	...	...	...	...	...
Trochosmilia	8	1	1	1	...	5	4
37	76	8	17	30	3	17	20
Class—ECHINODERMATA.							
Ananchytes	2	...	...	1	...	1	1
Antedon	1	...	...	...	...	1	...

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Caratomus	1	...	...	1	...	...	...
Cardiaster	13	1	1	6	1	2	...
Catopygus	2	1	...	1	1	1	7
Cidaris	23	1	...	6	4	9	...
Cottaldia	1	...	...	1	...	...	10
Clypeopygus	1	1	...	...	...	...	...
Cyphosoma	12	...	...	2	...	3	...
Discoidea	6	1	1	2	3	3	8
Echinobrissus	5	2	...	3	...	4	4
Echinopsis	1	...	...	...	...	...	1
Echinoconus	2	...	...	1	1	2	2
Echinus	2	1	...	1	...	...	...
Echinocyphus	2	...	...	1	1	...	...
Echinospatangus	1	1	...	1	...	...	...
Echinothuria	1	...	...	...	...	...	1
Epiaster	2	...	...	2	...	1	1
Galerites	6	...	...	1	...	4	4
Goniophorus	2	...	...	2	...	...	...
Gonfopygus	1	...	...	1	...	...	...
Glyphocyphus	1	...	...	...	...	...	1
Hemiaster	6	...	3	2	1	2	...
Hemipneustes	2	1	1	...	...	...	...
Holaster	7	...	...	2	2	4	1
Holectypus	1	...	...	...	...	1	...
Hyposalenia	1	...	...	1	...	...	...
Infulaster	2	...	...	...	...	...	2
Micraster	6	...	...	...	...	3	4
Pedinopsis	1	...	...	...	...	1	...
Pseudodiadema	17	6	...	10	...	3	...
Peltastes	7	2	1	4	1	2	...
Pyrina	4	...	...	2	2	2	...
Pygurus	2	...	...	1	2	...	...
Salenia	13	...	...	5	2	7	2
Trematopygus	2	2	...	...	...	...	...
Toxaster	2	1	...	...	...	...	...
37	161	21	7	59	21	56	49
ASTEROIDEA.							
Arthraster	1	...	...	...	...	...	1
Goniaster	6	...	...	...	1	4	4
Goniodiscus	10	...	...	...	...	...	10
Oreaster	7	...	...	...	...	1	6
Stellaster	2	...	...	2	...	...	...
5	26	...	...	2	1	5	21
OPHIUROIDEA.							
Ophiura	1	...	...	...	...	1	1
CRINOIDEA.							
Bourgueticrinus	5	...	...	1	1	1	...
Glenotremites	1	...	...	1	...	1	4
Marsupites	3	...	...	...	...	...	3

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Pentacrinus	3	2	1	1	1	1	1
Torynocrinus	1	...	...	1	...	...	...
	13	2	1	4	2	3	8
Class—ANNELIDA.							
Ditrupa	2	...	...	...	1	1	1
Serpula	30	7	2	11	3	5	14
Vermicularia	8	4	3	3	1	...	1
Vermilia	1	1	...	1	...	...	1
	41	12	5	15	5	6	17
CLASS—CRUSTACEA.							
CIRRIPEDIA.							
Loricula	2	...	...	1	...	1	...
Pollicipes	10	1	3	3	...	3	1
Pyrgoma	1	...	...	...	...	...	1
Scalpellum	12	1	1	1	3	5	9
Verruca?	1	...	...	...	...	...	1
	26	2	4	5	3	9	12
ENTOMOSTRACA.							
Bairdia	5	1	1	2	4	3	...
Candona	1	1	...	...	...	...	...
Cypridea	4	4	...	...	...	...	...
Cythere	15	...	...	...	...	...	...
Cythereis	2	1	2	...	...	...	...
Cytherella	7	...	3	...	3	5	5
Cytherideis	1	...	1	...	...	1	...
Cytheropteron	1	...	...	...	1	...	1
Diaulax	2	...	2	1	...	...	...
Cyphonotus	1	...	...	1	...	...	...
Macrocypris	1	...	...	...	1	...	...
	40	7	9	4	9	9	6
MALACOSTRACA.							
Enoploclytia	4	...	...	...	1	4	2
Etyus	2	...	1	1	...	...	...
Eucorystes	1	...	...	1	...	...	...
Glyphæa	1	...	...	1	...	...	...
Graptus	1	...	...	1	...	...	...
Hemiöon	1	...	...	1	...	...	...
Homolopsis	1	...	1	1	...	...	...
Hoploparia	8	...	5	4	...	...	...
Mesostylus	1	...	...	...	...	...	1
Mesocrangon	1	...	1	...	...	...	...
Meyeria	3	3	...	...	...	...	...
Mithracites	1	1	...	...	...	...	...

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Necrocarcinus	3	...	3	3	1	1	...
Pagurus	1	...	...	...	...	...	1
Palæaga	1	...	...	...	1	...	...
Palinurus	1	1	...	...	...	...	...
Palæocorystes	3	...	2	1	...	1	...
Platypodia	1	...	...	2	...	1	...
Phlyctisoma	2	...	...	2	1	...	...
Podopilumnus	1	...	...	1	...	...	...
Plagiopthalmus	1	...	...	1	...	...	...
Scyllaridea	2	...	2	1	...	...	...
Trachynotus	1	...	...	1	...	...	...
Xanthosia	2	...	...	2	...	...	...
40	44	5	15	24	4	7	4
		Class—POLYZOA.					
Actinopora	4	1	...	...	...	...	3
Alecto	2	...	...	...	...	...	2
Atagma	1	...	...	...	...	...	1
Berenicea	5	...	2	2	...	...	2
Biflustra	1	...	...	...	...	...	1
Cavea	1	1	...	...	...	...	...
Cellepora	2	...	...	...	...	...	2
Cellulipora	1	...	...	1	...	...	...
Ceriocava	1	...	1	...	...	...	...
Ceriopora	8	6	...	5	...	...	...
Clypeina	1	...	...	...	...	...	1
Cricopora	2	...	...	1	...	1	1
Cresina	1	...	...	...	...	...	1
Desmeopora	3	...	...	2	...	...	2
Diastopora	5	2	...	1	..	...	2
Discopora	2	...	...	...	...	...	2
Domopora	1	...	...	...	...	...	1
Echinocava	1	1	...	...	...	...	...
Entalophora	2	2	...	...	...	...	...
Eschara	5	...	...	...	...	...	5
Escharina	2	...	...	...	...	1	2
Flustra	4	...	...	...	...	...	4
Flustrellaria	1	...	...	...	...	...	1
Heteropora	2	1	...	1	1	1	2
Hippothoa	1	...	...	...	...	...	1
Holostoma	1	...	...	...	...	...	1
Homœosolen	1	...	...	...	...	...	1
Idmonea	4	...	...	...	...	...	4
Laterotubigera	1	1	...	...	...	...	..
Lapholepis	1	1	...	...	...	...	...
Lunulites	1	...	...	...	...	...	1
Marginaria	1	...	...	...	...	...	1
Membranipora	1	...	...	...	...	...	...
Melecertites	1	1	...	...	...	...	1
Multicrescis	5	3	...	...	...	...	...
Nodelea	1	...	...	...	...	...	1
Petalopora	1	...	...	...	...	...	1
Proboscina	5	2	...	2	...	...	1

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Pustulopora	4	1	...	2	...	1	3
Quadricellaria	1	...	...	...	...	...	1
Radiopora	2	1	...	1	...	...	...
Reptocea	1	1	...	...	...	...	...
Reptomulticava	3	3	...	...	...	...	...
Reptotubigera	3	2	...	...	...	1	1
Reptelea	1	...	...	1	...	...	...
Retepora	3	...	1	1	...	...	1
Reticulipora	1	...	...	...	...	...	1
Siphoniotyphlus	1	...	...	...	...	...	1
Siphodictyum	1	...	...	1	...	...	1
Semieschariopora	1	...	...	...	...	...	1
Semimulticavea	1	1	...	1	...	...	...
Semimultisparsa	1	1	...	...	...	...	...
Semimulticresis	1	1	...	...	...	...	...
Spinopora	1	...	...	...	...	...	...
Stellocavea	1	...	...	...	...	...	1
Truncatula	1	...	...	...	...	1	1
Unicavea	1	...	...	...	...	...	1
Unitubigera	1	1	...	...	...	...	...
Zonopora	1	...	...	1	...	...	...
59	114	34	4	23	1	6	61
Class—BRACHIOPODA.							
Argiope	2	...	...	1	1	1	...
Crania	3	2	...	1	1	2	2
Discina	1	1	...	...	...	...	...
Kingena	1	...	1	1	1	1	1
Lingula	3	2	1	1	...	...	...
Magas	2	...	...	...	2	1	1
Rhynchonella	30	16	3	12	13	7	4
Terebratella	5	4	...	2	2	2	2
Terebratula	36	13	4	12	11	11	5
Terebratulina	4	3	1	1	2	1	1
Terebrirostra	2	1	...	...	1	1	...
Thecidium	2	1	...	1	...	1	1
Trigonesemus	2	...	..	...	1	1	1
Waldheimia	13	12	...	1	...	1	...
14	106	55	10	33	35	30	18
MONOMYARIA.							
Anomia	5	4	...	1	...	...	...
Avicula	15	8	1	5	1	...	...
Exogyra	18	16	3	7	3	3	3
Gervillia	5	4	1	1	...	...	...
Gryphæa	1	...	...	1	...	...	...
Hinnites	5	1	1	3	...	...	...
Inoceramus	25	4	5	8	6	11	10
Lima	34	15	5	14	3	10	7
Ostrea	22	6	4	11	3	5	11
Pecten	38	13	8	14	5	11	11

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Perna	11	2	1	9	...	...	...
Pinna	10	5	2	4	...	...	2
Plicatula	9	6	1	5	2	2	3
Spondylus	18	2	1	5	4	2	4
14	216	86	28	88	27	44	51
			DIMYARIA.				
Amphidesma	1	...	...	1	...	...	...
Anatina	2	2	...	...	...	...	...
Arca	16	10	3	2	2	2	...
Astarte	15	10	2	4	...	1	1
Cardita	6	3	1	2	...	1	...
Cardium	18	11	...	8	...	...	...
Chama	1	...	...	1	...	...	...
Corbis	4	3	1	...	...	...	...
Ceromya	1	...	...	1	...	...	..
Corbula	5	4	2	3	...	...	...
Corimya	2	2	...	...	...	...	...
Crassatella	1	1	...	...	...	...	...
Cryptodon	1	1	...	...	...	...	...
Cucullæa	4	3	1	3	...	...	...
Cypricardia	2	1	...	...	...	...	1
Cyprina	8	3	1	7	...	...	...
Cytherea	6	2	1	6	...	...	...
Diceras	2	1	...	...	...	...	1
Gastrochæna	2	1	1	...	...	...	...
Isoarca	2	1	...	1	...	...	...
Isocardia	3	2	3	...	...	...	1
Leda	7	3	4	2	...	1	...
Limopsis	1	...	...	1	...	...	...
Lithodomus	2	2	...	...	...	...	...
Lucina	9	4	2	4	...	...	...
Lutraria	2	...	...	1	...	1	...
Mactra	1	...	...	1	...	...	...
Modiola	8	5	1	5	...	1	1
Mya	2	1	...	1	...	...	...
Myacites	5	2	...	3	...	...	...
Mytilus	9	1	3	8	...	...	...
Neæra	2	...	2	...	...	...	...
Nucula	19	5	13	11	...	...	...
Opis	3	2	...	...	1	1	...
Panopæa	5	5	2	2	...	...	...
Pachyma	1	...	...	1	...	...	...
Pectunculus	2	1	1	1	...	...	...
Periploma	1	...	1	...	...	...	...
Petricola	2	...	...	2	...	...	...
Pholadomya	10	4	1	2	1	1	3
Pholadidea	5	3	2	...	...	...	...
Psammobia	1	...	...	1	...	...	...
Solecurtus	2	1	1	...	...	...	...
Sphæra	4	1	...	...	...	...	...
Tellina	6	5	2	2	...	...	...
Teredo	2	...	...	...	1	1	2

Genera.	Number of Species.	Neocomian or Upper Greensand.	Albian or Gault.	Cenomanian or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Senonian or Upper Chalk.
Thetis	3	1	1	2	...	1	...
Thracia	3	3	1	...	...	...	...
Trigonia	29	9	4	17	3	1	...
Unicardium	1	...	...	...	...	1	...
Venus	12	6	...	5	1	1	...
51	261	125	57	111	9	14	10
Class—GASTEROPODA.							
Acmæa	2	...	1	1	...	...	...
Actæon	5	3	2	...	1	...	...
Anisomion	1	1	...	...	...	...	...
Aporrhais	28	7	14	11	2	6	...
Avellana	8	2	6	1	1	1	...
Alvaria	3	2	1	...	...	...	...
Brachystoma	1	...	...	1	...	...	...
Buccinum	1	...	...	1	...	...	...
Calyptræa	1	...	...	...	...	...	1
Cadulus	1	...	1	...	...	...	...
Cassidaria	1	...	...	...	...	1	...
Crucibulum	1	1	...	...	...	...	...
Cerithium	16	8	8	1	1	1	...
Crepidula	2	...	...	2	...	...	...
Cinulia	2	...	...	2	...	...	...
Columbellina	2	...	...	...	2	...	...
Delphinula	1	1	...	...	...	...	...
Dentalium	9	...	3	6	1	1	...
Dimorphosoma	10	5	2	1	2	...	...
Dolium	1	...	...	...	...	1	...
Disoketa	1	...	...	1	...	...	...
Entalis	1	...	1	...	...	...	...
Emarginula	11	3	...	4	2	2	1
Eulima	3	2	1	...	...	1	...
Funis	4	...	1	2	...	...	1
Fusus	14	1	10	7	...	...	2
Gibbula	1	...	...	...	1	...	...
Helicaulax	1	1	...	...	1	...	...
Hipponyx	1	...	...	...	...	...	1
Helicon	1	1	...	...	...	...	...
Littorina	8	2	1	4	...	...	1
Mesochilostoma	1	...	...	1	...	...	...
Murex	2	...	2	...	...	...	...
Narica	2	...	1	1	...	...	...
Nassa	2	...	...	2	...	...	...
Natica	14	3	5	7	...	...	...
Nerinæa	1	...	...	1	...	...	...
Nerita	1	...	...	1	...	...	...
Neritopsis	2	1	...	1	...	...	...
Ornithopus	4	...	...	2	2	...	...
Phasianella	5	1	1	4	...	...	...
Patella	1	...	...	...	...	...	1
Pleurotoma	1	...	...	1	...	...	...
Pileopsis	3	1	1	1	...	...	...
Pleurotomaria	19	4	5	8	3	4	4

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albien or Gault.	Cénomanien or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Sénonian or Upper Chalk.
Pterocera . .	6	3	1	4	1	1	1
Puncturella . .	1	...	...	1	...	...	...
Pterodonta . .	3	...	...	3	...	...	...
Pyrula . . .	3	...	...	2	...	...	1
Pyrgiscus . .	3	...	1	2	...	...	...
Rissoina . .	2	...	2	...	...	...	...
Rostellaria . .	6	2	3	...	1	1	...
Scalaria . . .	17	8	3	6	...	1	1
Scurria . . .	2	2	...	...	...	...	...
Solarium . . .	17	3	5	10	1	2	1
Stomatodon . .	1	...	...	1	...	...	...
Siphodentalium .	2	...	2	...	...	...	...
Tectura . . .	4	2	2	...	...	...	...
Tornatella . .	2	1	...	1	...	...	...
Tessarolax . .	1	...	...	...	1	...	...
Tridactylus . .	1	...	1	...	...	...	...
Trochus . . .	11	2	2	2	1	2	2
Turbo . . .	7	3	...	...	...	3	1
Turboidea . .	1	...	...	...	1	...	...
Turritella . .	7	2	2	2	...	1	1
Voluta . . .	1	...	...	...	1	...	...
66	298	78	91	108	26	29	20
HETEROPODA.							
Bellerophonia . .	1	...	1	...	...	...	...
Class—**CEPHALOPODA.**							
Ammonites . .	128	29	35	14	29	31	9
Ancycloceras . .	12	9	2	...	1	1	...
Anisoceras . .	2	...	2	...	...	1	...
Baculites . .	4	...	1	1	1	2	1
Belemnitella . .	5	...	...	...	1	2	4
Belemnites . .	8	5	3	3	2	2	...
Conoteuthis . .	1	...	1	...	...	...	...
Crioceras . .	6	4	...	1	...	...	1
Hamites . . .	24	8	12	3	...	2	1
Helicoceras . .	4	...	4	...	...	...	1
Nautilus . . .	20	12	3	6	9	7	2
Ptychoceras . .	1	...	1	...	...	...	...
Scaphites . .	5	...	2	1	1	2	1
Turrilites . .	20	...	6	2	11	11	1
Aptychus . .	6	...	...	...	...	...	6
15	246	67	72	31	55	61	27
CLASS—PISCES.							
PLACOIDEI.							
HYBODONTIDÆ.							
Hybodus . .	3	1	...	...	...	1	1

CESTRACIONTIDÆ.

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albien or Gault.	Cénomanien or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Sénonian or Upper Chalk.
Acrodus . . .	3	...	...	...	...	2	3
Aulodus . . .	1	...	...	...	...	...	1
Dephanophorus .	1	...	...	...	...	1	1
Plethodus . .	2	...	...	...	..	2	2
Ptychodus . .	15	...	1	2	...	6	14
Strophodus . .	2	1	...	...	...	...	1
6	24	1	1	2		11	22

LAMNIDÆ.

Lamna . . .	4	2	2	3	...	3	3
Odontaspis . .	1	...	...	...	...	...	1
Oxyrhina . .	3	...	...	1	...	..	2
Scylliodus . .	1	...	...	...	...	...	1
4	9	2	2	4		3	7

NICTITANTES (SQUALIDÆ).

Corax . . .	2	...	...	1	...	1	2

EDAPHODONTIDÆ.

Edaphodon . .	5	...	..	1	...	...	2
Ischyodus . .	2	1	...	...	...	1	...
2	7	1		1		1	2

NOTIDANIDÆ.

Notidanus.	2	...	...	...	...	1	2

SQUALIDÆ.

Otodus . . .	2	...	..	1	1	1	1

GANOIDEI.

SAUROIDEI.

Lophiostomus . .	1	...	...	...	...	...	1
Belonostomus . .	2	...	...	...	...	2	2
Caturus . . .	1	...	...	...	...	...	1
Pomognathus . .	1	...	...	...	...	1	1
Prionolepis . .	1	...	...	...	...	1	1
5	6					4	6

PYCNODONTIDÆ.

Cælodus . . .	2	...	1	1	...	...	...
Pycnodus . .	4	...	...	...	...	2	4
Acrotemnus . .	1	...	...	...	...	...	1

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albien or Gault.	Cénomanien or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Sénonian or Upper Chalk.
Gyrodus . .	3	...	1	...	...	...	4
Microdon . .	3	...	...	...	...	...	3
Phacodus . .	2	...	...	...	...	...	2
6	15	0	2	1		2	14
LEPIDOIDEI.							
Lepidotus . .	2	1	...	...	...	...	1
CŒLACANTHI.							
Macropoma . .	3	1	...	1	1	...	1
PELECTOGNATHI.							
Dercetis . . .	1	...	...	...	...	1	1
GYMNODONTIDÆ.							
Orthagoriscus .	1	...	...	...	...	...	1
CYCLOIDEI.							
SALMONIDÆ.							
Acrognathus . .	1	...	...	...	...	1	...
Aulolepis . .	1	...	...	...	...	1	1
2	2					2	1
SCOPELIDÆ.							
Osmeroides . .	3	...	...	...	...	1	3
Tomognathus . .	2	...	...	...	...	...	2
2	5					1	5
SCOMBERIDÆ.							
Coelorhynchus .	1	...	...	...	...	...	1
Enchodus . .	2	...	...	...	...	...	2
Tetrapterus . .	1	...	...	...	...	1	1
3	4					1	4
MUGILIDÆ.							
Calamopleurus .	1	...	...	...	...	...	1
SPHYRÆNIDÆ.							
Cladocylus . .	1	...	...	...	...	1	1
Daptinus . .	1	...	...	...	...	1	...
Hypsodon . .	2	...	...	...	...	...	2
Saurodon . .	1	...	...	...	...	...	1
Pachyrhizodus .	2	...	1	...	...	...	1
Saurocephalus .	2	...	...	...	...	2	2
Ichthyodectes .	2	...	...	...	...	1	1
Erisichthe . .	1	...	...	...	...	1	1
Portheus . .	3	...	1	...	1	1	...
9	... 15		2		1	7	9

CTENOIDEI.

PERCIDÆ.

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albien or Gault.	Cénomanien or Upper Greensand.	Chalk Marl.	Turonian or Lower Chalk.	Sénonian or Upper Chalk.
Berycopsis	1	...	...	...	...	1	1
Beryx	4	...	...	...	...	...	4
Stenostoma	1	...	...	...	...	...	1
Homonotus	1	...	...	...	...	...	1
4	7					1	7

CLASS—REPTILIA.

DEINOSAURIA.

Acanthopholis	4	...	...	3	1	1	...
Acrodontosaurus	1	...	...	...	1	...	...
Anoplosaurus	2	...	...	2	...	...	...
Eucercosaurus	1	...	...	1	...	...	...
Macrurosaurus	1	...	...	1	...	...	...
Iguanodon	1	1	...	...	...	...	...
Syngonosaurus	1	...	...	1	...	...	...
7	11	1		8	2	1	

CROCODILIA.

Crocodilus	1	...	...	1	...	...	...
Polyptychodon	2	1	...	1	...	1	1
2	3	1		2		1	1

LACERTILIA.

Coniosaurus	1	...	...	...	...	...	1
Dolichosaurus	1	...	...	...	...	1	...
Dakosaurus	1	...	1	...	...	...	...
Leiodon	1	...	...	...	...	...	1
Mosasaurus	1	...	...	...	...	...	1
Raphiosaurus	2	...	1	...	...	1	1
6	7		2			2	4

ENALIOSAURIA.

Acrodontosaurus	1	...	...	...	1	...	...
Cetarthrosaurus	1	...	...	1	...	...	...
Ichthyosaurus	1	...	1	1	1	1	...
Manisaurus	1	...	1	...	...	...	...
Nanisaurus	1	...	1	...	...	...	...
Plesiosaurus	6	1	...	4	...	2	1
6	11	1	3	6	2	3	1

PTEROSAURIA.

Coloborhynchus	3	...	...	2	...	1	...
Pterodactylus	4	...	...	...	...	4	...
2	7			2		5	

CHELONIA.

Genera.	Number of Species.	Neocomian or Lower Greensand.	Albien or Gault.	Cénomanien or Upper Greensand.	Chalk Marl.	Turonien or Lower Chalk.	Sénonian or Upper Chalk.
Chelone . . .	5	...	...	1	...	2	3
Emys . . .	6	...	...	6	...	...	...
Testudo . . .	1	...	...	1	...	...	...
Trachydermochelys	1	...	...	1	...	...	...
4	13			9		2	3

ORNITHOSAURIA.

Ornithocheirus .	2	...	...	2	...	...	...

Class—AVES.

Enaliornis . .	2	...	...	2	...	...	...

PART VIII.

CAINOZOIC OR TERTIARY PERIOD.

CHAPTER L.

GENERAL VIEW OF THE EOCENE OR NUMMULITIC GROUP.

History.—Great geographical changes, or change between the relative position of land and sea, took place at the close of the Mesozoic (Cretaceous) period both in Western and Central Europe. The floor of the Cretaceous sea was partly elevated so as to become estuarine, constituting shallow marine areas. All forms of life that had previously existed slowly and entirely died out; none lived through those changes, which must have occupied a vast period of time.

Denudation of the Chalk.—We have full evidence of the extreme denudation which the Chalk underwent prior to the deposition of the oldest Tertiary beds. This extended denuded surface points to a great gap, or epoch of unrepresented time, between the close of the Secondary and the commencement of the older estuarine Tertiary series. Europe at present shows no data exhibiting the transitional condition that must have occurred between the Upper Chalk and the overlying Sands (Thanet, or other equivalent beds).[1] This hiatus doubtless represents one of the greatest breaks in the successive depositions or sedimentation of the British rocks, if not in the history of the Eastern Hemisphere.

The Tertiary Period chronicles the development of the modern distribution of land and sea, and the commencement of most of the great mountain-chains. The rocks deposited during the early Tertiary Period possess local characters distinguishing them from all previously known; compared with other and older rocks, they are loose and incoherent in structure, presenting marked local variations, showing that they were mainly accumulated in detached basins of comparatively limited extent, and in seas so shallow as to be at times filled up, resulting in their becoming brackish or even freshwater.

In England the transition from the Cretaceous to the Tertiary series is distinct and positive, neither can we say that at any point on the continent of Europe any community of species exists. The *Cre-*

[1] Sables de Bracheux.

taceous fauna, numbering 584 genera and 2270 species, became totally extinct prior to the deposition of the lower Tertiary series. All history of the change, geographically and palæontologically, is lost; but the alteration of fauna was complete, resulting in the introduction or appearance of no less than 4270 new species, which now constitute the known British Tertiary fauna. Numerically the species in the several (17) horizons are:—The Thanet sands $\frac{45}{73}$, Woolwich and Reading beds $\frac{72}{125}$, London clay $\frac{247}{640}$, Bracklesham beds $\frac{201}{695}$, Barton $\frac{123}{851}$, Upper Bagshot $\frac{17}{23}$, Headon beds $\frac{112}{286}$, Osborne beds $\frac{10}{12}$, Bembridge beds $\frac{30}{58}$, Hempstead $\frac{24}{53}$, Miocene $\frac{32}{58}$ (Plantæ), Coralline crag $\frac{295}{871}$, Red crag $\frac{203}{601}$, Norwich crag $\frac{156}{329}$, Pleistocene freshwater $\frac{165}{254}$, Pleistocene marine $\frac{211}{538}$.

I. *Eocene Strata.*

The most familiar European types of Eocene deposits occur in the Anglo-Parisian, Anglo-Belgian, and Franco-Belgian basins, which contain alternations of marine, estuarine, and freshwater strata.

Flora and Fauna.—In the English Eocene series several distinct floras have successively occurred, those of the London clay (15 genera and 110 species), and the Bagshot beds (34 genera and 47 species), being the richest both in types and species. The plants of the London Clay indicate a hot and humid climate, and include species of palms, *Nipadites*, &c., also Leguminosæ through 12 species, *Leguminosites* 18, and *Faboidea* 25 species; Sapindaceæ through *Cupanoides* and *Tricarpelloides* 15, Malvaceæ through *Hightea* 10, the Proteaceæ through *Pterophylloides* and *Comptonia* 9 species.[1]

The Eocene fauna shows that in Central Europe tropical or subtropical conditions prevailed. The Nummulites of the Nummulite Limestones, with other Foraminifera in vast numbers, attest their importance in the construction of the Middle Eocene rocks of Europe, Persia, and India.

The Mollusca played a most important part in the fauna of the Eocene and other or later rocks of the Tertiary period. Most of the genera now living commenced their career in the sea that laid down the London Clay, Bracklesham and Barton beds; and no less than 300 genera and 1000 species appeared in the British Lower Eocene sea.

Most of the Gasteropoda are now confined to the warmer seas of the globe. The most abundant genera in these older Tertiary strata were *Nautilus*, *Voluta*, *Conus*, *Mitra*, *Melania*, *Cerithium*, *Rostellaria*, *Turritella*, *Pleurotoma*, *Cypræa*, *Natica*, *Fusus*, *Cancellaria*, *Oliva*, *Pseudoliva*, *Pyrula*, *Murex*, *Ancillaria*, &c., &c. Amongst the Pelecypoda may be mentioned *Pholadomya*, *Cytherea*, *Cardita*, *Cardium*, *Crassatella*, *Cyprina*, *Cyrena*, *Modiola*, *Nucula*, *Pectunculus*, *Psammobia*, &c. The London Clay and Bracklesham beds yield

[1] See Bowerbank: "Fossil Fruits of the London Clay." J. S. Gardner: "British Eocene Flora," Palæontographical Soc., 1879.

numerous fish-remains, no less than 70 genera and 125 species having lived in these continuous deposits. Those genera most richly illustrated are *Ætobatis*, *Lamna*, *Myliobatis*, *Phyllodus*, *Otodus*, *Pristis*, &c. Remarkable also are the Birds in the English Eocenes, 7 genera and 7 species occurring in the London clay, viz., *Argillornis*,[1] *Dasornis*, *Enaliornis*, *Halcyornis*, *Lithornis*, *Macrornis*, and *Odontopteryx*.[2] This last possesses teeth on its bill, and shows Pterosaurian affinities.

The Upper Eocene beds in the Paris basin have also yielded an avian fauna of extreme importance, carrying back in time the ancestors of many existing genera, now of almost tropical habitat, such as the flamingo, ibis, pelican, and hornbill, &c.[3]

The researches of Gaudry[4] and Gervais[5] into the Vertebrate fauna of the Tertiaries of France have brought to light the remains of the numerous mammalian genera for which Tertiary time was so pre-eminently distinguished. The Lower Eocene period is marked by the appearance of *Arctocyon primævus* and *Palæonictis*, the two most ancient of the Tertiary mammals of Europe. The former is allied to the Bears in its dentition, and to the Marsupials in the low organisation of its brain; while the second (*Palæonictis*) "possessed teeth resembling the Australian *Dasyure*." To this period belong also the tapir-like *Coryphodon*,[6] which likewise inhabited the Lower Eocene land of France, Switzerland, and North America; and the hog-like *Hyracotherium*, having teeth similar to those of the peccary, with a form intermediate between that of the hog and the hyrax (or coney), and the allied genus *Pliolophus* of the London Clay.

The tapir-like animals, *Palæotherium*, *Paloplotherium*, *Lophiodon*,[7] and *Pachynolophus*, with the Lemuroid *Cœnopithecus*, the earliest representative of the monkeys, distinguish the Middle Eocene Period from the Lower and Upper. Besides the older tapiroid genera, transitional forms appeared, having characters intermediate between those of the tapiroid *Palæotheres* and the *Equidæ*. Such were *Anchitherium*, *Diplopus*, *Microchœrus*, *Hyopotamus*, hog-like animals; and hornless forms of deer, &c., *Dichodon*, *Dichobune*, *Amphitragulus*. *Cynodon* among the carnivora resembled the wolf, *Amphicyon* the

[1] Owen: Q. J. Geol. Soc., vol. xxxvi. p. 23; *ib.*, vol. xxxiv. 1878.

[2] *Ib.*, vol. 1873, p. 511.

[3] Alph. M. Edwards: "Oiseaux Fossiles," vol. ii., p. 543. Dawkins: "Early Man in Britain," p. 73. See also article on Fossil Birds, by Smith Woodward, in "Science Gossip."

[4] "Les Enchainements du Monde Animal," &c. 8vo. Paris, 1878.

[5] "Zoologie et Palæontologie Françaises," 2d ed., 2 vols. 1859, *et passim*.

[6] Professor Marsh has proved that "*Coryphodon* inhabited America, and that it was a five-toed tapiroid animal, possessing all the characters of the sub-order Perissodactyla" (B. Dawkins, *loc. cit.*, p. 27).

[7] This genus, which occurs in Britain at Bracklesham, is the only well-defined mammalian species. In France it is also associated with two tapiroid genera (*Pachynolophus* and *Pro-Palæotherium*), and animals allied to the hogs and omnivorous carnivores (*Anchilophus*, *Dichobune*, *Heterohyus*).—Gervais, *loc. cit.*, p. 327; *ib.* Boyd Dawkins, *loc. cit.*, p. 30.

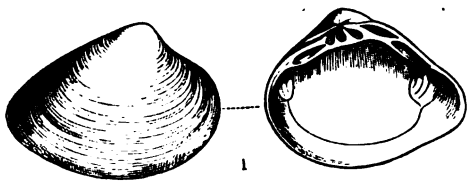
PLATE XXIX.

LOWER AND MIDDLE EOCENE FOSSILS.

1. *Cyrena cuneiformis* (Sow.) Woolwich and Reading beds (Plastic Clay). Charlton, Upnor, &c.
2. *Melania* (*Melanatria*) *inquinata* (Defr.) Plastic Clay. Woolwich, New Cross, Plumstead.
3. *Rostellaria Sowerbyi* (*Aporrhais*) (Mant.) London Clay Series. Herne Bay, Highgate, Bognor, Watford.
4. *Voluta nodosa* (Sow.) Middle Eocene. Barton, &c.
5. *Phorus extensus* (Sow.) London Clay. Highgate, Sheppey, Bognor, &c.
6. *Pyrula reticulata?* Middle Eocene. Bracklesham.
7. *Voluta ambigua* (Brand.) Middle Eocene. Barton.
8. *Do. athleta* (Sow.) Middle Eocene. Barton, Bracklesham.
9. *Terebellum convolutum* or *sopita* (Brand.) Middle Eocene. Barton, Bracklesham.
10. *Terebellum fusiforme* (Lam.) Barton and Bracklesham.
11. *Crassatella sulcata* (Sow.) Middle Eocene. Barton.
12. *Cardita sulcata* (Brander). Middle Eocene. Barton, Hordwell.

PLATE XXIX.

LOWER AND MIDDLE EOCENE FOSSILS.



1

2

4

5

3

MIDDLE EOCENE.

8

12

6

11

7

9

10

fox, and *Tylodon* was allied to the wolverine or glutton (*Gulo luscus*), all or most of these possessing marsupial affinities.[1]

The labours and learning of Leidy, Marsh, and Cope of America have brought together a mass of new matter relative to the herbivorous perissodactylate Ungulata of that continent, *Eohippus*,[2] and others, probably ancestors of the horse. They have also thrown light upon the Deinocerata, represented in the Middle Eocene Tertiaries of North America by the gigantic *Deinoceras* (*D. mirabilis*), regarded by Professor Cope as an aberrant group of Ungulates; but by Professor Marsh as a distinct order, intermediate between the *Perissodactyle Ungulates* and the *Proboscidea*. Professor Marsh considered them as being of the size of elephants, and resembling them in osteology, while possessing the habits of the rhinoceros,[3] and bearing three pairs of horn cores, or six horn-like prominences, one on each cheek, a pair on the snout, and another pair on the forehead.

Range.—The Lower and Middle Tertiaries of Britain are entirely confined to the south and south-east of England, and the sediments of both areas were accumulated in synclinal depressions in the Chalk, answering to the so-called "basins" of London and Hampshire, although the conditions of sedimentation and life (or the stratigraphy and faunal contents) of the two areas differ essentially. In each the strata are divisible into 3 groups or series, *an upper, middle, and lower*, the Hampshire basin having only 4 subdivisions, as compared with those of the London area with 7.

	London Basin.	Hampshire Basin.
Upper.	1. Upper Bagshot sands.	1. Barton clay.
Middle.	2. Middle Bagshot beds, part of Lower Bagshot sands.	2. Bracklesham beds and leaf beds of Bournemouth and Alum Bay (Isle of Wight).
Lower.	3. *a.* Part of Lower Bagshot sands.	
	b. London clay.	3. *b.* London clay (Bognor beds).
	c. Oldhaven beds (N. Kent).	
	d. Woolwich and Reading beds.	*d.* Woolwich and Reading beds.
	e. Thanet beds.	

[1] Gaudry, *loc. cit.* Introduction, p. 4, Terrains.

[2] *Eohippus*, the oldest member of the Equidæ, discovered by Marsh in the Lower Eocene of New Mexico. *Orohippus* occurs in beds slightly higher. This genus comprises small equine animals allied to Eohippus.

[3] Professor Marsh includes among the Deinocerata the genera *Deinoceras*, *Uintatherium*, and *Tinoceras*, this last genus being the *Loxolophodon* of Cope. See Leidy, "Extinct Mammalia from Nebraska Territory," 1852. *Ib.* "Dakota and Nebraska," 1869. *Ib.* "Extinct Vert. Fauna of the Western Territories," 1873. Professor Marsh: "Gigantic Foss. Mammalia of the Order Deinocerata," Amer. Jour. Sci. and Arts, 1873. Cope: "Short-footed Ungulata of the Eocene of Wyoming," Proc. Amer. Philosoph. Soc., 1873.

TABLE C.—*Subdivisions of the Eocene Series, tabulated chiefly through the researches of Professors Prestwich and Edward Forbes, &c.*

Eocene.	Upper.	Hempstead beds.	Corbula beds.	Fluvio-marine Series [1] (Oligocene).
			Upper. Middle. Lower. — Freshwater and Estuarine marls.	
		Bembridge beds.	Bembridge marls.	
			„ limestone.	
		Osborne beds.	St. Helen's sands.	
			Nettlestone grits.	
		Headon beds.	Upper.	
			Middle.	
			Lower.	
	Middle.	Bagshot beds.	Upper Bagshot sand.	
			Middle „ — Barton clay. Bracklesham bed.	
			Lower „ — Sand and pipeclay, with pebble beds.	
	Lower.	London Tertiaries.	London clay and Bognor beds (upper *London* Tertiaries).	Lower London Tertiaries.
			Oldhaven beds.	
			Woolwich and Reading beds (plastic clay).	
			Thanet beds.	

The term Oligocene is useful in classifying foreign Tertiary strata, and as such is advocated by some English palæontologists. With us it may be convenient, provided that no marked break in either flora or fauna is implied.[2]

The accompanying Table shows the complete history of the Eocene, Miocene, and Oligocene Tertiaries, as proposed by Forbes, Lyell, Judd, and Gardner, and the change in nomenclature if adopted.[3] The classification adopted by these authors is that of the Geological Survey, as proposed by Edward Forbes in 1856 (see 4th column); the proposed change (*if used*) is indicated in column 3d; and that of Professor Judd in column 7 will show their correlation.

[1] The Oligocene of Beyrich, Von Kœnen, and Judd, *loc. cit.* Von Kœnen in 1854 extended to the English beds of the Hampshire basin the classification adopted in North Germany, and originally proposed by Professor Beyrich, in which the term "Oligocene" is employed to designate the lowest beds of the North German Tertiaries.

[2] The Upper Oligocene is not represented in England.

[3] Besides the references to the above five authors, the paper by Messrs. Tawney and Keeping on the beds at Headon Hill, and Colwell Bay in the Isle of Wight (Q. Jour. Geol. Soc., vol. xxxvii. pp. 85–127), should be consulted by all students.

TABLE CI.—*Showing the Historical Classification of the British Tertiary Rocks and the Value or Application of the German Oligocene in Britain.*

Geol. Mag., 1882.[1]	Classification if Oligocene be not adopted.	Classification, if "Oligocene" be used.	Forbes, *Surv. Mem. I. of Wight*, 1856.	Lyell, *Student's El.*, 1878.	Von Kœnen, *Q.J.G.S.*, 1863.	Judd, *Q.J.G.S.*, 1880.
C. OLIGOCENE.	LOWER MIOCENE.	*Middle Oligocene.* Hempstead marine. Bembridge freshwater marls (including Hempstead do.), with a marine oyster band near base.	Hempstead marine. Hempstead Upper freshwater. ,, Middle ,, ,, Lower ,,	*L. Miocene.* Hempstead marine. Hempstead freshwater. [Bovey Tracey beds].	*Middle Oligocene.* Hempstead beds, &c.	*Middle Oligocene.* Hempstead series. "Bembridge group."
	UPPER EOCENE.	Bembridge Limestone, freshwater. Osborne Marls, freshwater. Upper Headon, freshwater.	*Upper Eocene.* Bembridge Marls with oyster band. Bembridge Limestone. Osborne Marls, freshwater. Upper Headon, ,,	Bembridge fluvio-marine. Osborne or St. Helens.	Upper Headon.	
L. OLIGOCENE.	MIDDLE EOCENE.	*Lower Oligocene.* Middle Headon, marine (includes Brockenhurst bed). Lower Headon, freshwater.	Middle Headon, marine. Lower Headon, freshwater.	*Upper Eocene.* Headon series, marine and freshwater, including sands at base of Headon Hill. (H. Hill Sand.)	*L. Oligocene.* Middle Headon, including Brockenhurst bed. Lower Headon.	*Lower Oligocene.* ['Brockenhurst series.] "Headon group."
UPPER EOCENE.		*Upper Eocene.* Upper Bagshot Sands, of Hampshire, estuarine. Barton Sands and Clays.	*Middle Eocene.* Upper Bagshot Sands. Barton beds. Bracklesham or Middle Bagshot.	Barton Sands and Clays.	*U. Eocene.* Upper Bagshot Sands, *l. c.* p. 99. Barton Clay.	*U. Eocene.* Barton Clay.
MIDDLE EOCENE.		*Middle Eocene.* Middle Bagshot or Bracklesham. Lower Bagshot, including Hengistbury, Bournemouth [or Bovey ?] beds.	Lower Bagshot.	*M. Eocene.* Bracklesham or Bagshot series, including Bournemouth beds.	*M. Eocene.* Bracklesham series, &c.	
LOWER EOCENE.	LOWER EOCENE.	*Lower Eocene.* London Clay. Oldhaven pebble beds. Woolwich, brackish. Thanet Sands, marine.	*L. Eocene.* London Clay. Woolwich and Reading beds. Thanet Sands.	*L. Eocene.* London Clay. Woolwich and Reading series. Thanet Sands.	*L. Eocene.* London Clay, &c.	

[1] J. S. Gardner's classification.

CHAPTER LI.

LOWER EOCENE STRATA: THANET SANDS, WOOLWICH AND READING SERIES, OLDHAVEN BEDS, AND LONDON CLAY.

1. *Thanet Sands.* Prestwich, 1850.
Landénien (Dumont).
Suessonien (d'Orb).
Soissonien et Flandrien (Mayer).
Sables Marins de Bracheux.

Characteristics.—At the base of the Woolwich and Reading series there usually occurs a series of marine sands, which are developed in the Isle of Thanet and in the London basin wherever the Upper Chalk and Lower Eocene beds are exhibited. They occur as a thick bed of pale yellow, greenish sand and loam, occasionally clayey, and containing at their base a thin but persistent layer of *green-coated flints, which rest immediately upon the eroded surface of the Chalk.* The type localities in the London area where the Thanet beds are best exposed are Chislehurst, Crayford, Charlton, Well Hill (outlier), Epsom, St. Mary Cray, Sittingbourne, &c. The Thanet beds thin out westward and northward of London. Their junction with the Chalk may be observed in many places, especially in Kent at Chislehurst, Crayford, Erith, Plumstead, Lewisham, Dartford, and Gravesend; and in Essex, at Purfleet and Gray's Thurrock chalk pits. The greatest thickness of the Thanet sand is about fifty feet. The beds are well exposed in the cliffs of Pegwell Bay, also east of Herne Bay, in the pits at Charlton near Woolwich, and south of London in many railway-cuttings. They are not known further west than Windsor, and do not occur in the Hampshire basin.

Fauna.—It is only in the London basin that the Thanet sands appear to have been deposited. Their thickness is variable; under London it is about 20 feet, in West Kent 50 to 60 feet. The Fauna of the Thanet sands comprises 45 genera and 73 species. The Foraminifera, Pelecypoda, and Gasteropoda are those groups most largely illustrated, and comprise respectively $\frac{8}{16}$, $\frac{20}{24}$, and $\frac{19}{24}$. The characteristic bivalve-shells are *Ostrea bellovacina, O. cymbuloides; Pecten Prestwichii, Astarte tenera, Cardium Laytoni, Cucullæa decussata, Glycimeris rutupiensis, Nucula margaritacea, N. Thanetiana, Panopœa granulata, Pholadomya cuneata, Sanguinolaria Edwardsii.* Gasteropoda—*Aporrhais Sowerbyi, Fusus tuberosus, Ringinella turgida, Scalaria Bowerbankii.*[1]

[1] For detailed history of the Thanet beds, see Whitaker, Mem. Geol. Survey, vol. iv., part 1, pp. 55–97, where they are exhaustively treated; "Thanet Sands," Prestwich, 1852; "Thanet Beds," Geol. Surv., 1852. They contain no layers of rounded black flint pebbles. The entire fauna of the Thanet sands is $\frac{45}{73}$ species, the Mollusca alone representing $\frac{19}{37}$. $\frac{33}{45}$ species pass to the Woolwich and Reading beds and $\frac{14}{45}$ to the London clay. 12 out of the 19 classes named in the table are not represented in the Thanet sands group. The *Foraminifera, Pelecypoda* (2 groups), *Gasteropoda, Cephalopoda,* and *Fishes* are the only classes illustrated. We have much still to learn relative to this early Eocene period.

2. *Woolwich and Reading series.*
Lignites du Soissonnais (à Cyrena cuneiformis).

Characteristics.[1]—The "*Plastic clay*" of the earlier geologists. There are two types in this division of the Lower London Tertiaries which bear the above names. The Woolwich beds occur only in the S.E. part of the London area and the Hampshire basin, their most southerly extension being Whitcliff Bay and Alum Bay in the Isle of Wight. At Woolwich they are characterised by the presence of green, yellow, and white sandy laminated clay, full of marine and estuarine univalve shells belonging to the genera *Cerithium*, *Pitharella*, *Melania*, *Melanopsis*, and *Paludina*, with *Ostrea*, *Cyrena*, *Corbula*, and *Unio*, &c., among the bivalves.

The rocks of this division of the Lower London Tertiaries are extensively distributed both as regards *main masses* and outliers, showing the former extension over the London and Hampshire basins. They appear in Berkshire and Hampshire, Surrey, Kent (St. Mary Cray, Erith, along the valley of the Thames above Erith, Upnor, Newington, Charlton, and Lewisham). In the London area (Surrey) they occur at Nunhead, Dulwich, Bromley, Chislehurst, and Wrothingham. In the Canterbury district these beds are abnormal in condition, being more sandy and less rich in organic remains. In Berkshire (Reading), where the term "Reading series" was first applied by Professor Prestwich, they are zoologically nearly unfossiliferous, but contain numerous plant-remains resembling the assemblage at Bournemouth and Alum Bay. North of the Thames, in Oxfordshire and Buckinghamshire, the extension of these estuarine clays and sands is instructive, showing their distribution over the Chalk area as outliers, and marking the geographical extension of the Eocene sea, or lower boundary of the Tertiaries, around the London basin, where seen beneath the superincumbent gravels, the removal of which would reveal the true extent of the edge of the synclinal depression of the Chalk wherein they were deposited. Much of the main mass in Middlesex and Hertfortshire is seen in sections at Bushey, near Watford, Watford Heath, Hatfield Park, and near Hertford.[2]

Conditions of Deposition.—Mr. Prestwich, in his valuable memoir

[1] "Woolwich and Reading Series," Prestwich, 1854; "Woolwich and Reading Beds," Geol. Survey, 1878. These were formerly described as the "Plastic Clay" by Webster, 1816; "Plastic Clay Formation," Lyell, 1827 (and Prestwich 1854); "Mottled Clay," Prestwich, 1846. The presence of the Woolwich and Reading beds between the London Clay and the Chalk is very constant; they comprise deposits of freshwater, estuarine, and marine origin, and of different lithological structure. The Marine molusca greatly resemble those of the Thanet sands, but the Estuarine shells are highly characteristic. The thickness of the beds varies from 15 to nearly 100 feet in the London basin; in the Hampshire basin (Isle of Wight, &c.), from 80 to 170 feet; Alum Bay, 84 feet; Whitcliff Bay, 165 feet.

[2] The most complete history of the succession and distribution of the Woolwich and Reading beds is given in the Mem. of the Geol. Survey, vol. iv., part 1, by Mr. Whitaker, pp. 98–238. It is in itself a manual of these beds in the London basin.

upon the Woolwich and Reading series,[1] has shown the conditions of deposition to be due to oscillation and intermittent movements, giving rise to (1) *Terrestrial*; (2) *Fluviatile* and *Estuarine*; and (3) *Marine* conditions. The first are observable between Hungerford and Reading on the west; the second, between London, Woolwich, Gravesend, and Upnor in the central area; while the third, or Marine, commences with Boughton and Herne Bay on the east—thus tracing the area of the Tertiaries longitudinally along the valley of the Thames from Hungerford, the most westerly extension of the main mass, to the Reculvers on the east.

The transverse areas are probably due to waves of oscillation governing both drainage area and level, especially in the central area (*Fluviatile* and *Estuarine*). The eastern deep-sea area, where the Thanet sands are greatly developed, is almost entirely wanting west of London, between Hanwell and Newbury. These three areas, as described by Professor Prestwich, give the key to the structure of the London Basin and its intricate Tertiary geology, physically and palæontologically. "This" (as Mr. Prestwich remarks) "once determined, after eliminating the two more uniform groups above and below," it becomes apparent that there is, in the Lower London Tertiaries, "a defined order of superposition found in *three distinct* and independent *groups of strata*." It is the extremely variable character of the Woolwich and Reading beds that produces the impression of a want of order recurring throughout the whole of the Lower Tertiaries, and it was not until this middle division had received from Mr. Prestwich careful research that the threefold division of the Lower London Tertiaries was finally determined in the following recognised order:—

I. The Basement-bed of the London Clay.
II. The Woolwich and Reading series.
III. The Thanet sands.

Range.—Throughout the Isle of Wight, and the western portion of the London Tertiary area, this middle group, or Woolwich and Reading series, consists of unfossiliferous red, green, blue, and white mottled clay. As it approaches London, strata of laminated and carbonaceous clays, shingle beds of flint pebbles, with fluviatile and estuarine shells, set in and replace the mottled clays. Still further east, it becomes less pebbly and argillaceous, passing at last into light-coloured pure quartzose sands, with a marine fauna. Viewed horizontally, this group may be divided into three distinct geographical areas, each having characters of its own.[2]

West.	Central.	East.
Sands and mottled clays (Reading and the Isle of Wight).	Pebble beds, sands, and laminated clays (Woolwich, Blackheath, and Bromley).	Quartzose and Glauconiferous sands (Herne Bay and Canterbury).

[1] Q. Journ. Geol. Soc., vol. x. pp. 75–170.

[2] There cannot well be strata varying more in appearance and character than the Woolwich beds, in the separate sections at Reading, Deptford, Blackheath, and Herne Bay.

Hampshire.—In the Isle of Wight, at Whitecliff Bay, on the east side of the island, and Alum Bay on the west, and immediately adjacent to the Chalk, the deep-red mottled clays of the Woolwich Series are finely shown; no organic remains have as yet occurred in these clays. Northward of the Isle of Wight, beneath Southampton, the beds between the London Clay and the Chalk consist entirely of mottled clays about 80 feet thick.

Dorset.—In Dorsetshire the Woolwich beds are exposed at Studland Bay, and near Weymouth beds referable to this age also occur. The so-called Hertfordshire Pudding Stone is on the same horizon.

TABLE CII.—*Showing the Classification adopted by Mr. Prestwich in 1854, and that of the Geological Survey at the present time, mainly through the continued work and research of Mr. Whitaker.*

Prestwich, 1850–54.			Whitaker, 1866.	
London Clay		Clay.		
Lower London Tertiaries.	Basement bed of the London Clay.	*a.* Thin pebbly loam, &c., of the western part of the London Tertiary District.	Basement bed.	London Clay.
		b. Thin clayey pebble-bed of Lewisham, &c.		
		c. Highest sands of Upnor, the Reculvers, &c., with pebbles at the bottom.	Oldhaven beds.	Lower London and Kentish Tertiaries.
		d. Part of the sandy pebble-bed of Kent (Blackheath, Abbey Wood, Shottenden Hill, &c.)		
		e. Part of the sandy pebble-bed of West Kent (Sundridge near Bromley).		
	Woolwich and Reading Series.	*f.* Sands, shell-beds, mottled clays, lower pebble-beds (unfossiliferous and local) and pebbly greensands of West Kent and part of East Kent.	Woolwich and Reading beds.	
		g. Mottled plastic clays, sands, &c., of the western part of the London Tertiary District, and sands of East Kent.		
	Thanet Sands.	*h.* Sands, sandy marls, &c., &c.	Thanet beds.	

Fauna.—The entire fauna of the Woolwich and Reading beds comprises 72 genera and 123 species.

The characteristic marine Gasteropoda are *Cerithium gracile, C. funatum, Calyptræa trochiformis, Melanopsis ancillaroides, M. buccinoides, Pitharella Rickmanni,* and *Natica subdepressa.*

Marine Bivalves—*Arca Dulwichiensis, Cardium Laytoni, Corbula regulbiensis, Cyprina Morrisii, Cytherea orbicularis, Glycimeris rutupiensis, Modiola elegans, Pectunculus terebratularis,* and *Ostrea bellovacina.*

The Estuarine Species are *Melania inquinata, Paludina aspera, Hydrobia Parkinsoni, Cyrena cuneiformis,* and *C. cordata.*

[1] Whitaker, Q. Journ. Geol. Soc., vol. xxii.

FRESHWATER—*Unio Solandri, Dreissena serrata*, and *Planorbis hemistoma*.
MAMMALIA—the tapir-like *Coryphodon*. Turtles illustrate the Reptilia.
At Loampit Hill, Lewisham,[1] the Woolwich beds are well exposed, and about 50 feet thick, and with a pebble bed 12 to 14 feet in thickness. At Peckham, the thin Grey Limestone near the top contains *Paludina lenta, Pitharella Rickmanni*, and *Cyrena Dulwichiensis*.

The entire fauna and flora of the Woolwich and Reading beds number $\frac{72}{123}$, and those species that pass to or are common to the London clay $\frac{30}{45}$; Bracklesham beds $\frac{17}{17}$; and Barton beds $\frac{8}{8}$. This alliance is only through the Mollusca, Pelecypoda, *Monomyaria* $\frac{2}{8}$, to London clay; and $\frac{2}{4}$ Bracklesham. *Dimyaria* $\frac{16}{18}$ to London clay, and $\frac{4}{4}$ Bracklesham or $\frac{18}{23}$. No Cephalopoda are known in the Woolwich and Reading beds. Out of the $\frac{72}{123}$ species in the Woolwich fauna $\frac{22}{28}$ species pass up from the Thanet sands. These united faunas constitute the bases of the Eocene Group.

3. *Oldhaven beds* (*Whitaker*, 1866).
Oldhaven and Blackheath beds, Geol. Survey, 1872.

The name "Oldhaven beds," derived from Oldhaven Gap on the north-east coast of Kent, west of Reculvers, was proposed in 1866,[2] for the sands and pebble beds that come between the London Clay and the Woolwich beds in Kent,[3] and form the base of the London Clay. The structure or composition of the Oldhaven beds consists almost entirely of perfectly rolled flint pebbles in a fine sandy base. On the south-east of London the pebbly state prevails, showing false-bedding. The true basement bed of the London Clay overlies the series for which the name Oldhaven has been proposed

The Oldhaven beds appear to transgress or overlap the lowest divisions of the London Tertiaries, which lends strength to the conclusion that the planing down or denudation of the Chalk that once spread over the Wealden tract, began in Lower Eocene times, and that the pebble-beds of Bromley, Blackheath, &c., are one of the direct results of that denudation.

In the neighbourhood of Canterbury, at Shottendon Hill near Sittingbourne, at Rochester, Plumstead Common, Abbey Wood, Blackheath, and Woolwich, these beds are well exposed.

They are marine in origin, and contain a richer specific fauna than the Woolwich and Reading beds below, numbering 74 genera and 150 species; the groups richest in fossils are the Gasteropoda and Pelecypoda, the former numbering 30 genera and 64 species, the latter 24 genera and 60 species. The plant-remains show traces of *Ficus* and

[1] For full details of structure and local sections, consult the paper by Prof. Prestwich, Q. Jour. Geol. Soc., vol. x. pp. 80–113.

[2] Whitaker, Q. Jour. Geol. Soc., vol. xxii. p. 412.

[3] Doubtfully classed by Mr. Prestwich with the basement bed of the London Clay, *ib.* vol. vi. and vol. x. Consult Whitaker, Mem. Geol. Surv., "Geol. of the London Basin" (Oldhaven beds), pp. 239–272. Every important section in the London Basin is described in this Memoir.

Cinnamomum,[1] resembling the succeeding Bogshot flora, but without the southern types which occurred in the later Eocene floras, and which have been described by Ettingshausen and Gardner.[2]

Along the southern boundary of the London Basin, the most westerly locality where the Oldhaven beds are seen is Croydon, beyond which they seem to thin out.

4. *London Clay* (Smith 1815).[3]

Sables Marins de Cuise-la-Mothe à Nummulites planulatus. Nummulitique inférieur, Italy, Germany, &c.

Character.—The mass of the London Clay presents throughout its whole range a uniformity of mineral structure so well marked and distinct, that either by this characteristic alone, or else by its organic remains (when present), it can be readily recognised. It is an argillaceous deposit of considerable thickness, varying from 300 to 400 or 500 feet.

Basement Bed.—Immediately at its base the London Clay contains a greater or less admixture of green and yellow sands, with rounded flint pebbles. These beds, however, seldom exceed a few feet in thickness. Mr. Prestwich gave the name "Basement-bed" to these sands and pebbles. A fauna of 80 species occurs in them.

Characteristic Fauna of the Basement-Bed.—The characteristic forms are *Aporrhais Sowerbyi*, *Calyptræa trochiformis*, *Cassidaria striata*, *Natica labellata*, *Cardium Laytoni*, *C. Plumsteadiense*, *Cytherea obliqua*, *C. orbicularis*, *Modiola elegans*, *Nucula* sp., *Panopea intermedia*, *Pectunculus brevirostris*, *P. Plumsteadiensis*, and *Ditrupa plana*.

The pebbles in the Basement-bed are remarkable for their occurrence over a very large area, throughout which they serve as a valuable means of separating the London Clay from the preceding or underlying Reading beds, even in the absence of fossils. The pebbles in this Basement-bed when gently struck with the hammer fall to pieces, and they are usually *black*, as contra-distinguished from those at the base of the Thanet sands, which are *green-coated*.

The London Clay is a deposit of stiff brown and bluish-grey Clay,

[1] These 2 genera indicate a warmer climate than we enjoy at present, and they are found in all the Tertiary floras.

[2] Palæontographical Soc., vol. 1879.

[3] This name was employed by Mr. Wm. Smith in 1815 to designate most of the Clay deposits above the Chalk. Prof. Prestwich first definitely separated the true London Clay from other and similar Eocene clays which had been confounded with it; he also recognised the "*basement bed*" which marks the incoming of the London Clay sea. The fauna and flora of the London Clay are both extensive and characteristic. The term "*Bognor beds*" applied by Professor Prestwich to a portion of the London Clay (1846–47), is not used except to call attention to a locally distinct lithological character. The thickness of the London Clay varies from a few feet in Wiltshire, and from 50 to 60 feet in Berkshire, to 500 feet in the south of Essex.

with layers of septarian nodules of argillaceous limestone. It is typically developed in the area of depression called the London Basin, and attains its maximum thickness (500 feet) in the south of Essex, and in the Hampshire Basin, both in the Isle of Wight and the mainland, where it is partly represented by the Bognor beds.[1] At Whitecliff and Alum Bay, on the south side of the island, it is conspicuous in the vertical cliffs of the two bays,[2] but the beds differ both lithologically and palæontologically from the typical strata occurring in the London Basin. Professor Rupert Jones estimates that the depth of the sea in which the London Clay was deposited, as indicated by the Foraminifera, may have been about 100 fathoms, or 600 feet. Professor Prestwich has shown that there are traces of Palæontological Zones in the London Clay,—the *lowest* indicating, in the east of the area of deposit, a maximum depth of water (500 feet), while a progressive shallowing is seen by higher zones, the uppermost of which contains the chief part of the terrestrial flora, as well as the fish and reptilian remains, all of which are well seen in the Sheppey beds.

Fauna and Flora of the London Clay.—The total fauna and flora of the London Clay, or those of the two basins united, comprise 246 genera and 640 species. The London Basin yields 192 genera and 420 species.

(Of these the Plantæ are 15 genera, and 110 species), or the 16 classes contain the following, numerically given :—Plantæ $\frac{15}{110}$, Foraminifera $\frac{1}{6}\frac{7}{0}$, Cœlenterata $\frac{1}{1}\frac{9}{7}$, Annelida $\frac{1}{8}$, Cirripedia $\frac{1}{5}$, Crustacea $\frac{1}{1}\frac{1}{8}$, Polyzoa $\frac{6}{7}$, Brachiopoda $\frac{2}{5}$, Pelecypoda $\frac{2}{1}\frac{5}{1}\frac{5}{0}$, Gasteropoda $\frac{4}{1}\frac{1}{4}\frac{1}{0}$, Pteropoda $\frac{1}{4}$, Cephalopoda $\frac{5}{1}\frac{5}{8}$, Pisces $\frac{4}{1}\frac{2}{2}$, Reptilia $\frac{5}{1}\frac{5}{5}$, Aves $\frac{1}{9}$, Mammalia $\frac{5}{8} = \frac{2}{1}\frac{1}{4}\frac{8}{0}$ genera and species ; only $\frac{6}{6}\frac{1}{0}$ of the 640 species pass to the Bracklesham beds, $\frac{1}{1}\frac{1}{7}$ to the Barton group, and $\frac{1}{1}\frac{1}{4}$ to the Headon. None pass higher.

The zoological relation between the London Clay and the Woolwich and Reading beds is $\frac{3}{4}\frac{0}{5}$; or, 30 genera and 45 species passed up from the Woolwich beds, so that the fauna of the London Clay is characteristic and distinctive. Deducting the 45 species that lived on from the Woolwich series, the special fauna is 595 species. Most of the 45 Woolwich and Reading forms are included among the 42 species that are common to the Oldhaven beds and the London Clay ; these facts clearly show that the fauna of the Woolwich and Reading and that of the Oldhaven beds constitute one horizon, the lowest Zone of the English Tertiaries.

[1] At Bognor (Sussex), beds of clay and calcareous sandstone occur on the shore ; and excavations at Portsmouth have revealed the same beds. The Barns Rocks between Selsea and Bognor, the Round Gate and Street Rocks on the west, and Mixen rocks to the south of Selsea, are portions also of the same beds. Septaria, or cement stones (clay ironstone), which abound in the London Clay, have been largely used in the manufacture of Roman cement ; they are dredged for off Harwich and in Chichester Harbour, and collected off Southend. They occur in abundance at Sheppey, where the London Clay is finely exhibited and nearly 500 feet thick.

[2] *Vide* Prestwich (Q. Jour. Geol. Soc., vol. ii.), "On the Tertiary or Supra-Cretaceous Formations of the Isle of Wight, as exhibited in the Sections at Alum Bay and Whitecliff Bay." Also (Mem. Geol. Survey), "Tertiary Fluvio-Marine Formation of the Isle of Wight," 1856 ; and "Geology of the Isle of Wight," by H. W. Bristow and R. Etheridge, Mem. Geol. Survey, 1862.

Palæontology of the London Clay.

Plantæ.—The flora of the London Clay is both extensive and remarkable, including, as stated, 15 genera and 110 species.

The chief genera hitherto known are *Callitrites* (4 species), *Cupanoides* (9), *Faboidea* (25), *Frenilites* (4), *Hightea* (10), *Leguminosites* (9), *Nipadites* (13), *Pterophylloides* (7), *Sabal* (1), *Solenostrobus* (5), *Tricarpellites* (7), *Xulionosprionites* (2). Besides these, which are chiefly fruits or seeds, and have long been known from Sheppey and one or two other localities, we have recently (through the researches of Ettingshausen) been enabled to add the following genera from Sheppey: *Pinus*, *Callitris*, *Salisburia*, *Musa*, *Elais*, *Iriartea*, *Livistona*, *Ocnocarpus*, *Quercus*, *Liquidambar*, *Nyssa*, *Diospyros*, *Symplocos*, *Magnolia*, *Juglans*, *Eucalyptus*, *Amygdalus*, and *Bankinia*, also fruits belonging to *Apocynaceæ*, *Cinchonaceæ* and *Cucurbitaceæ*.[1] Scarcely a single species of the known 110 passes to higher beds; the flora of the Lower and Upper Bagshot beds being entirely distinct.[2]

The ferns of the Lower Bagshot horizon, chiefly from Bournemouth, have received most careful research from Mr. J. S. Gardner in his monograph, in which he clearly shows the sub-tropical nature of the Bournemouth and Alum Bay fossils, the only exceptions being, probably, some species of *Pteris* and *Osmunda*. In a table constructed by Mr. Gardner to show the distribution and alliances of the British Eocene Ferns, we see their early geographical distribution and stratigraphical range for Europe, America, and the Arctic regions, as well as the geographical range of the nearest existing representatives.

The genus *Gleichenia* reached its maximum development in Europe in Pre-Eocene (Cretaceous) times; it is now found at Bournemouth in the Middle Eocene (middle Bagshots). The genus *Adiantum* occurs in Lower and Middle Eocene; *Pteris* through *P. eocenica* and *P. Bournensis*, Lower and Middle Eocene, Oligocene, and Miocene in Europe and Britain. The genus *Woodwardia*, Oligocene and Miocene, in Europe and Britain. *Goniopteris*, Middle Eocene, Oligocene, and Miocene, in Europe and Britain; and Eocene in America. *Phymatodes*, Middle Eocene (Europe); *Chrysodium*, Lower and Middle Eocene and Oligocene. *Osmunda*, Lower and Middle Eocene, Oligocene, in Europe and Britain, and Eocene in Arctic America. *Anemia*, Lower and Middle Eocene in Europe and Britain, Eocene in America. *Lygodium*, Middle Eocene and Miocene in Europe, and Eocene in America. *Marattia*, Lower Eocene—Europe and Britain. All the above 11 genera are British and belong to that group of rocks termed Bagshot.[3] The almost complete absence of any other herbaceous plants suggests that we are probably only acquainted with those ferns whose habits favoured their preservation.

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[1] See Mono., Brit. Eocene Flora, Pal. Soc., 1879, p. 12. Gardner and Ettingshausen.

[2] The species known in the Lower and Upper Bagshot sands and clays (or the beds below and above the Bracklesham and Barton series), which are so finely exposed in the cliffs at Bournemouth and Alum Bay, will be treated by Mr. Gardner in forthcoming volumes of the Palæontographical Society. We have placed the ferns of the Middle Bagshot beds, as given by Mr. Gardner, in the Bracklesham beds. The "Pipe Clay" flora has yet to be described. The work of De La Harpe requires confirmation with the newer stratigraphical views.

[3] Consult the table by Mr. Gardner of the more distinctive of the British Eocene Ferns, with their nearest fossil and recent or existing allies. Pal. Soc. 1880, p. 57. This table is full of suggestive evidence bearing upon their physical history, &c., and will show the value of the evidence we possess as to the history of the one group of plants in the fossil flora of the British Islands.

Rhizopoda.—*Foraminifera.*—This order constitutes an important element in the fauna of the London Clay, 17 genera and 56 species being known from both basins. We have no evidence that any of the London Clay forms pass up into the Bracklesham beds.

The chief genera are *Dentalina* (5 species), *Miliola* (3), *Nodosaria* (3), *Nodosarina* (23), *Planorbulina* (4), and *Textularia* (7). The metropolitan area has yielded 11 genera and 48 species out of the 17 and 56 known—*Nodosarina* with its sub-genera, *Dentalina* and *Nodosaria*, &c., being chiefly illustrated. Not a single species appears to be common to the London Clay and Bracklesham beds.

Actinozoa.—No corals are known below the London Clay,—in which occur 8 genera and 16 species, viz.:—

Dasmia Sowerbyi, Leptocyathus elegans, Mopsea costata, Paracyathus brevis, and *P. caryophyllus, Stephanophyllia discoides, Trochocyathus* (3 species) and *Turbinolia* (6 species), also *Oculina Wetherellii*; all are confined to the London Clay.

Echinodermata.—With two exceptions (*Hemiaster Branderianus* and *Ophiura Wetherellii*), the 16 known species are confined to the London Clay. They illustrate the following genera—*Astropecten* 3, *Bourgueticrinus* 1, *Cainocrinus* 1, *Cœlopleurus* 1, *Echinus* 1, *Goniaster* 3, *Pentacrinus* 3, *Schizaster* 1, and *Hemiaster* 2 species.

Crustacea.—18 genera and 26 species are essentially confined to this horizon; *none* came from the lower beds, and *none* pass to higher.

The chief genera are *Archæocarabus* (1 species), *Cyclocorystes* (1), *Dromilites* (2), *Goniochele* (1), *Hoploparia* (2), *Mithracia* (1), *Necrozius* (1), *Plagiolophus* (1), *Portunites* (1), *Thenops* (1), *Trachysoma* (1), *Xanthilites* (1), *Scyllarida* (2), *Xanthopsis* (5), *Litoricola* (2), *Palæocorystes* (1), *Rachiostoma* (2), *Ædisoma* (1 species). The *Ostracoda* are represented by 5 genera and 14 species.

Brachiopoda.—The only species in this group occurring in the London Clay is *Lingula tenuis*, which abounds in the calcareous sandstones of the Bognor beds, and in Septaria in the London basin; *Terebratulina striatula* is the only other species known.

Mollusca Proper; Pelecypoda (*Monomyaria*). *Anomia* (2 species), *Avicula* (3), *Ostrea* (9), *Pecten* (2), and *Pinna* 4 species, or $\frac{5}{20}$, are all that are known.

The characteristic species are *Anomia scabrosa, Avicula arcuata, Ostrea carinata, O. pulchra, Pecten corneus, P. duplicatus, Pinna affinis* and *P. pyriformis*; 8 of these 20 species pass to the Bracklesham beds; they are—*Anomia tenuistriata, Avicula media, Ostrea elegans, O. flabellula, O. elephantopus, O. tenera, Pecten corneus, Pinna maryaritacea*; 4 live on to the Barton beds, and 3 of the same to the Headon, viz., *Anomia tenuistriata, Avicula media,* and *Ostrea flabellula.*

Pelecypoda.—*Dimyaria.*—Thirty genera and 90 species range through the London Clay of the two Basins. In the London area 58 of the known 90 species occur, and with 5 exceptions all the genera.

These exceptions are *Gastrochæna, Isocardia, Pholas, Psammobia* and *Solecurtus.* These are moderately shallow-water genera, and are well represented in the Bracklesham beds; 16 genera and 21 species pass up to the Bracklesham series; 11 genera and 14 species range to the Barton group. They are—*Corbula gallica, Corbula pisum, Leda minima, Nucula similis, N. Bowerbankii,*

Panopæa corrugata, *Cardita Davidsoni*, *Cultellus affinis*, *Lucina mitis*, *Modiola hastata*, *Pholadomya margaritacea*, *Psammobia compressa*, and *Solecurtus parisiensis*, —most of these are sub-Laminarian. *Panopæa corrugata*, *Nucula similis*, *Leda minima*, and *Corbula pisum* also pass up to the Headon beds; these form part of the long-range forms before mentioned.

Gasteropoda.—Forty-one genera and 141 species comprise the London Clay Gasteropoda, both for the Hampshire and London areas. The fauna in both basins is singularly alike, 38 of the 41 genera and 133 of the 141 species in the London or northern basin being the same.[1] Twenty-nine genera and 48 species pass to the Bracklesham, $\frac{6}{8}$ to the Barton, and $\frac{7}{9}$ to the Headon beds. No species occur in the Lower Bagshot sands between the London Clay and the Bracklesham beds, neither in the Upper Bagshots, nor between the Barton and Headon beds. A known rich flora occurs in both of these horizons, but its history has yet to be worked out.

The following are some of the more characteristic species:—

Aporrhais Sowerbyi, *Cancellaria lævisculcula*, *Cassidaria nodosa*, *Cypræa oviformis*, *Fusus Pyrus*, *F. porrectus*, *Murex minax*, *Natica labellata*, *Phorus extensus*, *Pleurotoma Wetherellii*, *P. symmetrica*, *P. fusiformis*, *Pyrula nexilis*, *P. Smithii*, *Rostellaria* (*Hippocrenes*) *ampla*, *Solarium canaliculatum*, *Terebra striata*, *Turritella sulcifera*, *Voluta denudata*, and *V. nodosa*.

The species of Mollusca occurring at Bognor we may enumerate separately; they constitute the chief portion of the London Clay fauna for that area:—*Monomyaria* 3. That the Bognor beds differ materially from the rest of the London Clay is due probably to the thinly-developed rocks. The group *Dimyaria* number 16 genera and 28 species, and the Gasteropoda 17 genera and 25 species. No Sepiadæ or Teuthidæ occur; the Cephalopoda are *Nautilus imperialis*, *N. regalis*, *N. Sowerbyi*, and *N. centralis*.

The 29 genera and 148 species that bridge over the Lower Bagshot beds and pass to the Bracklesham cannot be named for want of space, so with the $\frac{3}{4}\frac{1}{1}$ species that are common to the London Clay and the Barton series; but beyond the Headon beds there is no community of species, as we here enter upon the Estuarine and Freshwater series.

Cephalopoda.—Five genera and 13 species known.

The genera are Nautilus with 6 species, *Belemnosis* (1), *Beloptera* (2), *Belosepia* (3), and *Aturia* (1). *Belosepia sepioidea*, *Aturia zic-zac*, *Nautilus centralis*, and *N. imperialis* pass to the Bracklesham beds.

Pisces.—No less than 59 genera and 93 species are known to occur in the London Clay, and with one or two exceptions these are met with in the northern area. Only 9 genera and 12 species are common to the London Clay and Bracklesham series.

The nine genera are *Ætobatis* (1 species), *Carcharodon* (1), *Cœlorhynchus* (1), *Lamna* (2), *Myliobatis* (3), *Otodus* (1), *Periodus* (1), *Pycnodus* (1), and *Elasmodus* (1). Three species pass to the Barton—*Notidanus serratissimus*, *Myliobatis striatus*, and *Ætobatis subarcuatus*. The species from Bracklesham and Selsea belong to the Bracklesham beds, little or no London Clay being there exposed. The chief

[1] The rich collections made by the late Mr. Wetherell, of Highgate, and Mr. F. Edwards, from the London Clay of the Northern Area will readily account for this; but beyond that, this area has yielded the great mass of the Gasteropoda, being far richer in species than the London Clay of the Hampshire basin.

genera in the London Clay or those prolific in species are—*Lamna*, 6 species; *Myliobatis*, 14, 3 of which pass to the Bracklesham beds; *Phyllodus*, 12 (all confined). The remaining 48 or 50 genera are represented by only one species each.

Reptilia.—The chief feature in the Reptilia of the London Clay is the number of its Cheloniæ, this order alone containing 4 genera and 19 species:—*Chelonia* 10 species, *Emys* 6, *Trionyx* 1, and *Platemys* 2.

Out of the 47 species of Reptilia known in the Tertiary rocks, and of the 24 in the London Clay, 19 belong to the order Chelonia. The Ophidians are represented by *Palæophis longus* and *P. toliapicus*, and the order Crocodilia by two species—*Crocodilus toliapicus*, and *C. champsoïdes*. These all occur at Sheppey and Harwich; only 2 species out of the 24 (*Chelone convexa* and *C. longiceps*) pass to higher beds or the Bracklesham series.

Aves.—This class is represented in the London Clay by 7 genera and 7 species, some having remarkable characters. Only 1 species (*Macrornis tanaupus*) occurs through all the intervening strata between the London Clay and the Pleistocene Marine beds. In the Headon series this form stands alone. *Odontopteryx*, which occurs at Sheppey, appears to have been a web-footed bird, having jaws provided with bony teeth.

Mammalia.—In this class 5 genera and 6 species occur in and are all confined to the London Clay. *Coryphodon eocænus*[1] (Fam. *Coryphodontidæ*) is probably identical with the genus *Bathmodon* of Cope. This genus comprises large Tapir-like animals, all confined to the Eocene Tertiaries. *Didelphys Colchesteri* (Didelphidæ), true opossums, are met with in the Lower Eocene of the Paris and London Basins, *D. Colchesteri* occurred in the London Clay of Kyson in Suffolk, and closely resembles the existing American species of *Didelphys*. Several similar forms occur in the Miocene Tertiary, but no undoubted marsupials have been as yet detected in the Pliocene deposits. *Hyracotherium* (*H. cuniculus*), belonging to the Tapiridæ (Pachydermata), allied to the living Hyrax, is also from Kyson. These Perissodactyle Ungulates now exist in South America, the Malayan Archipelago, and China; at the present day *Tapirus* is the sole surviving member of the Tapiridæ. The second species, *H. leporinum*, was obtained from the London Clay of Studd Hill, near Herne Bay (Kent). *Pliolophus vulpiceps* and *Miolophus planiceps* also belong to the Tapiridæ.

[1] The genus founded by Prof. Owen upon fragmentary remains in Britain.

CHAPTER LII.

MIDDLE AND UPPER EOCENE: MIDDLE BAGSHOT BEDS AND BRACKLESHAM SERIES.

Bracklesham series with Cardita planicosta and Nummulites lævigatus.

Syn. { *Caillasses et Calc. Grossier Supérieur de Paris, Grignon, &c.*
Calcaire Grossier Inférieur de Chaumont Damery, &c., à Cerithium Giganteum et Nummulites lævigatus (Paris Basin).

THIS extensive and important series comprises the middle portion or fossiliferous division of the Bagshot beds.

History.—These beds take their name from the bay in which they are so characteristically developed. The main divisions extend from Wittering on the west to the Barn Rocks east of Selsea Bill, a distance of seven miles. The Bracklesham beds are also well developed at Whitecliff Bay, Isle of Wight. The Hampshire basin alone contains the nummulitic series, no fossiliferous representative being known in the London basin.

About a mile to the east of Selsea Bill is situated the "Park bed," the equivalent of the "Calcaire grossier" of Grignon, in the Paris basin.[1] It contains thousands of *Nummulina lævigata* associated with *Pernæ*, *Bullæ*, *Cypræa*, and *Solens*, besides the well-known coral *Litharæa Websteri*. The Park bed is situated close to the shore, and is accessible at low water.

Certain fossils have given names to the beds that range through the bay. The remarkable shells, *Cypræa Coombii*, the great *Cerithium* (*C. giganteum*), and *C. cornucopiæ*, *Cardita* (*Venericardia*) *planicosta*, *Turritella terebellata*, *Conus diadema*, &c., amongst many others, aid us to determine the beds stratigraphically. Locally, the "Barn bed," "Palate bed," "Cardita bed," the "Park," &c., serve to mark horizons of importance.

"No marine fossiliferous beds are known *below the lowest* at Bracklesham Bay, or until we reach the Bognor Rock of the London Clay at Bognor. The following shells range through the Bracklesham group, and are confined to it, viz., *Cardita planicosta*, *Sanguinolaria Hollowaysii*, *Solen obliquus*, *Cytherea suberycinoides*, *Voluta cithara*, *Turritella sulcifera*, and *Pecten corneus;* the last-named species occurs in the High Cliff beds. The whole series is divided into four principal groups.[2]

[1] Quart. Journ. Geol. Soc., vol. xviii. pp. 66–75.
[2] Four hundred species of Mollusca have been found in the French deposits.

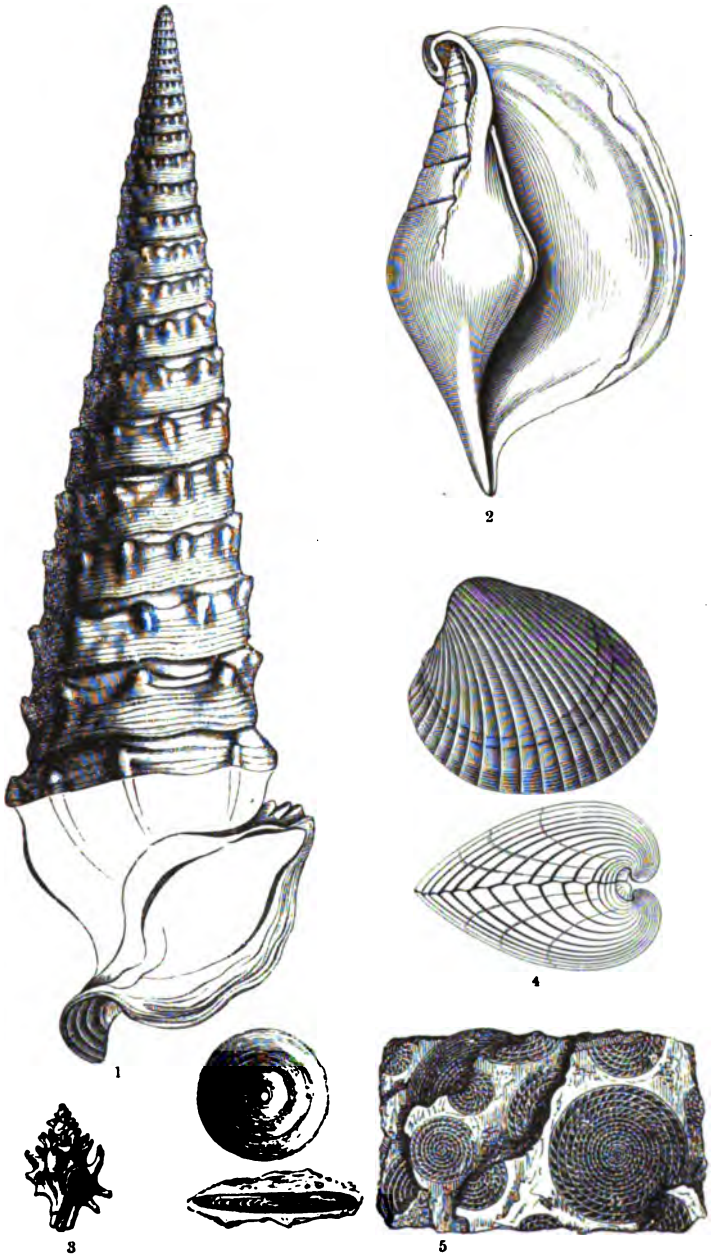
PLATE XXX.

MIDDLE EOCENE FOSSILS.

1. *Cerithium giganteum* (Lam.) Middle Eocene. Bracklesham, Grignon, &c., France.
2. *Rostellaria* (*Hippocrenes*) *macroptera* (Lam.) = *R. ampla* (Brander). Middle Eocene. Barton, Bracklesham. Lower Eocene (L. Clay). Kingston and Whetstone.
3. *Typhis pungens* (Brander). Middle Eocene. Barton, Alum Bay (Isle of Wight).
4. *Cardita* (*Venericardia*) *planicosta* (Lam.) Middle Eocene. Bracklesham.
5. *Nummulites lævigatus* (Brongn.) Middle Eocene. Bracklesham, Isle of Wight.

PLATE XXX.

MIDDLE EOCENE FOSSILS.



Group A, the upper, abounding in Gasteropoda, has *one of the fossil beds* in the eastern part of its range full of *Nummulina variolaria*.

Group B is more sandy in its general condition, and distinguished by the presence of the large Gasteropoda. *Cerithium gigantcum*, *Nummulina variolaria*, occur in this member at Whitecliff Bay.

Group C, sandy like the last, but its chief fossil-bearing bed is profusely crowded with *Nummulina lævigata*.

Group D embraces the lowest fossiliferous sands of Bracklesham Bay, the distinctive shells being *Cardita acuticosta*, and *Cyprœa tuberculosa*.

Bracklesham Beds at Whitecliff Bay.—These beds rest on the Lower Bagshot sands,[1] their base being distinguished by a bed of rolled flint pebbles about one foot in thickness. The Bracklesham beds here measure 650 feet in thickness, and it is important to compare them with the extent shown at low water in Bracklesham Bay, where they occupy the flat shore for three and a half to four miles, and are nearly horizontal, or slightly dip S. by E. with a strike of W. by S. and E. by N. So nearly level are these beds, that there is no opportunity for measuring their thickness with accuracy.

The Rev. O. Fisher[2] has given most accurate details of the 22 determined beds, in descending section or order, along 3 miles of the shore, dividing them into 4 groups, and stating the horizontal distance occupied by each of the 22 beds, with their outcrop in paces and with the observed characteristic fossils.

These 22 beds in the 3 miles occupy 5016 paces and show 22 step-like planes; and by no other method than that adopted by Mr. Fisher can they be understood.

A remarkable and rich fauna has been obtained from these sandy strata, numbering 171 genera and 653 species. Fractionally expressed it is as follows: Rhizopoda, $\frac{12}{20}$; Actinozoa, $\frac{15}{20}$; Echinodermata, $\frac{2}{2}$; Annelida, $\frac{2}{3}$; Cirripedia, $\frac{1}{1}$; Crustacea, $\frac{1}{3}$; Polyzoa, $\frac{2}{2}$; Brachiopoda, $\frac{1}{1}$; Pelecypoda, $\frac{40}{187}$; Gasteropoda, $\frac{70}{310}$; Cephalopoda, $\frac{4}{5}$; Pisces, $\frac{16}{32}$; Reptilia, $\frac{4}{6}$; Mammalia, $\frac{1}{1}$. Including the Plantæ, which comprise 34 genera and 47 species ($\frac{34}{47}$), the fauna and flora number 205 genera and 700 species ($\frac{205}{700}$). The Bracklesham series is vertical at Alum Bay, the lower portion consisting of yellow irony sands with alternating clays. These are believed to be equivalent to the lower Bagshot sands of the London Basin.

The upper part is a mass of alternating sands, variously and brilliantly tinted—red, orange, yellow, green, black, purple, and white, with some dark and light clays and layers of lignite and leaves.

These remarkable beds are the equivalents of the Bracklesham series in Bracklesham Bay. In Alum Bay these sands are poor in fossils, but, as we have seen, comprise a rich fauna in Whitecliff Bay, Southampton, and Bracklesham.

Stratigraphical relations.—The celebrated Bournemouth leaf-beds immediately underlie the true Bracklesham series, but (unlike those of Alum Bay) are of *Middle and not of Lower Bagshot* age, hitherto the

[1] Quart. Jour. Geol. Soc., vol. ii. [2] *Ibid.*, vol. xviii.

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1. *Cerithium giganteum* (Lam.) Middle Eocene. Bracklesham, Grignon, &c., France.
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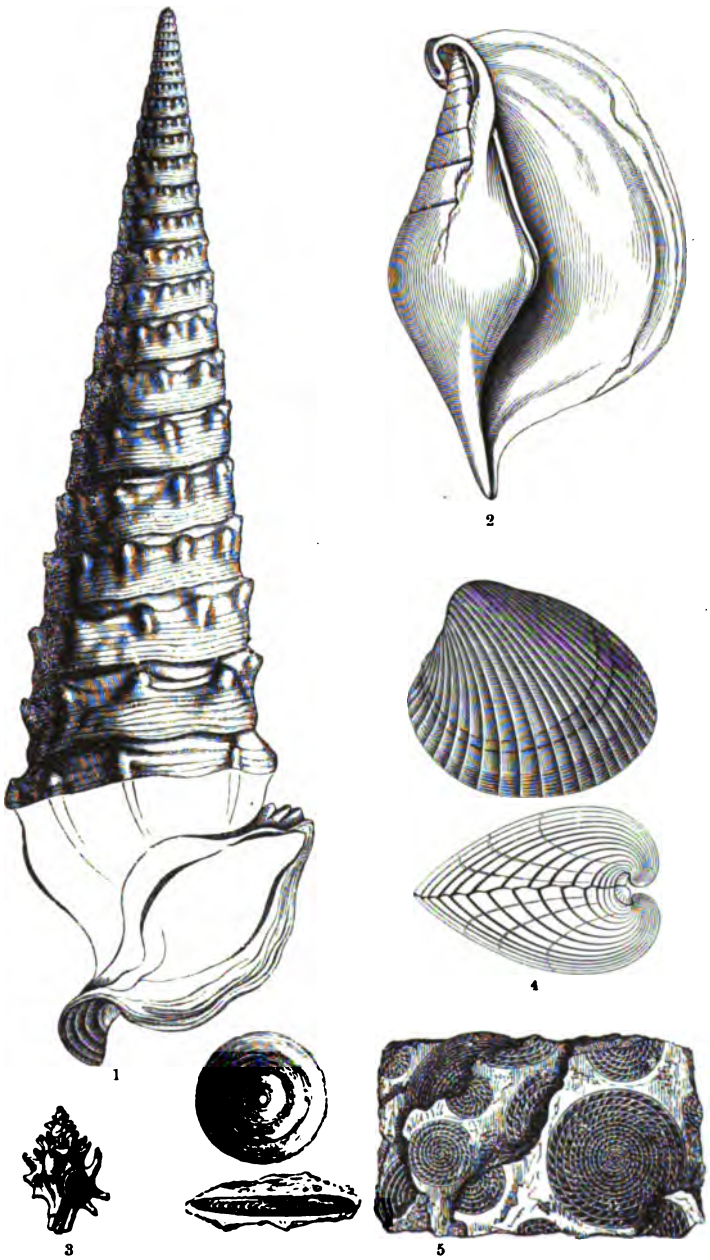
MIDDLE EOCENE FOSSILS.



received view. A great portion of the cliffs between Hengistbury Head and Bournemouth is of marine origin, and highly fossiliferous. These marine beds comprise two distinct characters, which may be correlated with the beds in Alum Bay.

At Highcliff, nearly under Rothsay Castle, both the Barton and the Bracklesham series are exposed, the Barton being not more than 10 feet and the subjacent Bracklesham 40 feet in thickness. The section is revealed to the sea-level, and therefore highly instructive. The remarkable promontory of Hengistbury Head is mainly composed of strata contemporaneous with the Bracklesham series. The cliffs at Hengistbury promontory facing the sea on the south are about 50 feet high, increasing to 100 feet on the north, both presenting bold escarpments. "The white sands at Highcliff are 30 feet thick, being 12 feet less than the equivalent beds at Alum Bay, where they measure about 42 feet." The lowest series in the cliffs at the headland are the "Boscombe sands," which without any doubt represent the chief mass of brilliantly coloured sands, about 750 feet thick, at Alum Bay. These coloured sands are numbered 25 and 26 in Professor Prestwich's section of the vertical beds in Alum Bay.[1] "The correlation of the Hengistbury Head series on the mainland with that of Alum Bay across the Solent admits of little doubt, and the beds would appear to be represented at Alum Bay by the *Highcliff sands*, 25 feet in thickness, and equivalent to Bed No. 28 in Professor Prestwich's section. The Hengistbury Head beds appear to be the equivalents of bed No. 27 in the Alum Bay section. The Boscombe sands represent beds No. 26 and 25 of Prestwich in Alum Bay, where they are 150 feet thick."

Marine Beds.—The flora of the Bournemouth beds may be referred to the Middle Bagshot series, and the Bracklesham division, possibly representing the same stage in the London basin, and it would appear from careful consideration of the Middle and Upper Bagshots that no Eocene beds younger than the Bracklesham are met with in the London area, a fact of much significance when compared with the complete succession of the Eocene series as developed in the Hampshire basin, and that of their equivalents in the basin of Paris.

Comparison of the flora of the two areas shows a close affinity, if not identity of species, *Osmunda lignitum*, *Lastræa Bunburyi*, *Palmacites dæmonorops*, the conifers and dicotyledons being not only specifically identical, but occurring in the same combinations and manner of preservation—*Polypodium*, *Chrysodium*, *Pteris*, and *Osmunda*, amongst the ferns; *Eucalyptus*, branches of *Sequoia*, pods and leaves of the Leguminosæ, *Nipadites*, *Dryandra*, *Cacti*, *Anona*, *Hightea*, &c., occur in the beds constituting the western termination of the Bournemouth marine series. The fauna testifies to its marine derivation; and includes *Ostrea*, *Arca*, *Modiola*, *Tellina*, *Calyptræa*, *Phorus*, *Natica*, and *Cerithium*. The changing physical characters of the beds of the Bournemouth series, both horizontally and vertically, the marshy character of the flora, "as represented by the ferns, aroids, Eucalypti, &c., the patches of clay, in which the water-plants, ferns, &c., may have

[1] Gardner: Quart. Jour. Geol. Soc., vol. xxxv. p. 202–228. 1879.

rooted, the local patches of ironstone, the intercalated marine beds and their fauna, mingled with *Unio*, clearly show that this was the debatable ground between sea and river, beyond which to the west it would appear the sea never then penetrated.

Freshwater Beds.—All the strata between Bournemouth and Poole harbour are of freshwater origin, and highly interesting on account of the fossil flora occurring in them—undoubtedly the most extensive, richest, and most varied hitherto extracted from the Tertiary formations. The cliffs comprising the Bournemouth freshwater series extend from Poole harbour on the west to beyond Bournemouth, and present escarpments averaging about 100 feet in height, composed of yellow, white, orange, and black sands and clays.[1] No less than nineteen species of ferns have been described from these beds. Only ten species have been met with in all the other British Eocene deposits, including the famous Bovey-Tracey beds, and three of these ten are also found at Bournemouth. The Bournemouth flora, which is distinct from the older or Alum Bay series, passes up into the so-called Oligocene without any perceptible change or break.[2]

These Middle Bagshots are represented in Alum Bay by the unfossiliferous beds marked 19 to 24 in Professor Prestwich's section (*loc. cit.*), and are 240 feet thick. Palæontologically, these beds may be correlated with the continental Eocenes, probably with those of Aix-la-Chapelle. The chief interest attached to the Bournemouth beds is the flora distributed chiefly through the "*Lower or Freshwater Series.*" None of the prevailing Alum Bay types are found at Bournemouth, nor are any of the well-known Bournemouth types found at Alum Bay; their affinities appear to be completely with the floras ascribed in France to the Oligocene, and the grouping as at present known, chiefly Australian and tropical American.

Probably a "great river may have existed here throughout the whole of Eocene times, bringing deposits from the westward, and the Bournemouth cliffs may represent a section across its bed; these deposits being formed during a continued period of subsidence." "The sudden change observed in the beds from fine to coarse sediment, and the thickness of the deposit, cannot be explained by the floods and freshets incidental to changing seasons, but are such as would occur *whenever subsidence exceeded*, in however trifling a degree, the silting-up power of the river."

The *Lower Freshwater series* is seen in the neighbourhood of Corfe and some parts of the cliffs at Studland. It is characterised by abundance of pipe-clays, and is about 200 feet thick.

The *Middle Freshwater series* also occurs at Corfe and Studland,

[1] Sir Charles Lyell in 1826, Professor Prestwich in 1848, the Rev. O. Fisher in 1861, and Mr. John Starkie Gardner in 1873, prepared a "Description and Correlation of the Bournemouth Beds." Part I., the Upper Marine Section, treating of the coast section between Bournemouth and Highcliff (Q. J. G. S., vol. xxxv.); and a second paper, Part II., on the lower or Freshwater series (*Ibid.*, vol. xxxviii.)

[2] Quart. Jour. Geol. Soc., vol. xxxviii. pp. 1-15. See also Mem. Geol. Survey of Great Britain, "Fluvio-marine Formation of the Isle of Wight," by Forbes, Bristow, and Etheridge (pt. 2).

and forms the whole thickness of the cliffs between Poole Harbour and Bournemouth, thus constituting a fine section, 4 miles long and 100 feet in height.

The Upper series is marine, and about 400 to 500 feet thick. This marine group occupies the cliffs between Boscombe and High Cliff.

Bournemouth Flora.—This appears to consist principally of trees or hardwood shrubs, few remains of herbaceous plants being preserved. The ferns are rare in the lower part of the series, but become more abundant, almost to the exclusion of other vegetation, towards the close of the middle period.

The prevailing group appears to be that of Acrostichum, of which there are many species; *Angiopteris*, *Nephrodium*, *Gleichenia*, *Lygodium*, and other undescribed forms occur.

Among the Coniferæ we find *Cupressus*, *Taxodium*, and *Dacrydium*, with indications of *Pinus*. The Cycadeæ seem to have disappeared.

The Monocotyledons are well represented by reeds and rushes. *Nipadites* illustrates the Screw Palms. The palms are very abundant, especially in the lowermost beds of Corfe and Studland and the upper Middle beds of Bournemouth; many *Flabellaria*, *Sabal*, and *Phœnicites* occur; the Smilaceæ, represented by 5 or 6 species, are in all the fossiliferous beds.

The Apetalæ are illustrated by *Populus*, *Ulmus*, *Laurus*, *Quercus*, *Artocarpidium*, and *Daphnogene*, with *Carpinus*, *Fagus*, *Castanea*, *Salix*, *Ficus*, and numerous *Proteaceæ*.

The Polypetalæ are represented by *Elæodendron*, *Rhamnus*, *Prunus*, *Juglans*, *Cluytia*, *Ceratopetalum*, with *Dodonæa*, *Celastrus*, *Eucalyptus*, and many *Leguminosæ*.

Cactus and *Stenocarpus* are added for the first time to the Eocene Dicotyledons.

The Eocene flora presents us with types peculiar to the Southern Hemisphere, and related to those of Australia and the adjacent islands. Examples of this southern flora occur through the Proteaceæ, Leguminaceæ, Coniferæ, and the Myrtaceæ through *Eucalyptus*.

Characteristic Fauna of the Bracklesham Beds.—Among the more characteristic fossils in the Hampshire basin are *Nummulina lævigata*, *N. variolaria*,[1] and the following:—

ACTINOZOA.—*Solenastræa*, *Stylocœnia monticularia*, *Turbinolia Dixoni*, *Dendrophyllia dendrophylloides*, and *Litharæa Websteri*.

PELECYPODA.—*Avicula media*, *Ostrea flabellula*, *O. tenera*, *Pecten corneus*, *P. squamula*, *Pinna margaritacea*, *Arca appendicula*, *A. tegulata*, *Cardita planicosta*, *C. elegans*, *Cardium semigranulatum*, *Chama squamosa*, *Clavagella coronata*, *Corbula longirostris*, *C. striata*, *Crassatella sulcata*, *Cultellus affinis*, *Cypricardia pectinifera*, *Cytherea elegans*, *C. trigonula*, *Mactra semisulcata*, *Modiola elegans*, *M. consobrina*, *Nucula similis*, *N. Dixoni*, *Pectunculus*

[1] Although the genus *Nummulites* is not abundant in England, it nevertheless plays an important part in the Eocene deposits of Central and Eastern Europe and Asia.

pulvinatus, Pholodomya margaritacea, Psammobia compressa, Sanguinolaria Hollowaysii, Solen obliquus, Tellina (21 species), *T. obovata, T. donacialis.*

GASTEROPODA.—*Actæon sulcatus, Ancillaria canalifera, Bifrontia marginata, Bulla extensa, Calyptræa obliqua, Cancellaria evulsa, Cassidaria nodosa, Cerithium* (36 species), *C. cornucopiæ, C. elegans, C. giganteum, Conus deperditus, Cyprœa Coombii, C. inflata, Fissurella Edwardsii, Fusus longœvus, F. scalaris, Globulus scalariformis, Hypocrenes* (*Rostellaria*) *ampla, Leiostoma* (*Fusus*) *pyrus, Marginella ovulata, Mesalia affinis, Melania truncata, Mitra volutiformis, Murex asper,* and *M. minax, Natica hybrida, N. patula, Oliva Branderi, Pleurotoma* (40 species), *P. attenuata, P. concina,* and *P. granulata, Pyrula nexilis, Rostellaria rimosa, Scalaria acuta, S. decussata, Scaphander* (*Bulla*) *lignaria, Sigaretus canaliculatus, Solarium canaliculatum, S. trochiforme, Strepsidura armata, Terebellum* (*Seraphs*) *fusiforme, Turritella imbricataria, T.* (*Mesalia*) *sulcata, Typhis pungens, Voluta* (28 species), *V. horrida, V. selsiensis,* and *V. reticosta.*

CEPHALOPODA.—*Belosepia brevispina, Nautilus imperialis.*

PISCES.—*Ætobatus marginalis, Carcharodon angustidens, Edaphodon Bucklandi, Lamna elegans, Myliobatis Dixoni, M. Edwardsii, Otodus lanceolatus.*

REPTILIA.—*Chelone convexa, C. trigoniceps, Gavialis Dixoni,* and *Palæophis typhœus.*

MAMMALIA.—*Lophiodon minimus.*

Faunal Value.—As the break between the Middle and Upper Eocene takes place at the close of the Bracklesham series, and as the Barton Clay (according to some systematists) is the only representative of the Upper Eocene, the faunal value of the two formations, and their zoological relationship one to the other, becomes an important question. The whole fauna of the Bracklesham series numbers, as we have seen, 201 genera and 695 species; the fauna of the Barton series, 123 genera and 351 species, almost exclusively Molluscan. The Bivalves include 35 genera and 114 species, and the Univalves (Gasteropoda), 60 genera and 196 species; or, united, the Mollusca of the Barton Clay comprise 95 genera and 310 species out of the entire fauna of 123 genera and 351 species. Thus, 88 per cent. of the Mollusca are common to the two horizons.

Middle Bagshot Beds. Barton Clay.[1] (*Upper Eocene.*)

Syn. { *Bartonien,* Meyer, 1857.
Parisien Supérieur, D'Orb.
Lækenien, Dumont.

Middle Bagshot Beds.—These comprise the Barton beds, and the overlying sands to the base of the Headon series. These sands may be passage beds, and the name "*Upper Estuary or Barton Sands*" has been suggested for them. Professor Judd proposes to unite the whole of the sands above the Barton beds at Hordwell to the Headon series.

The Barton Clay forms an important feature in the Hampshire Basin, where at the cliffs of Hordwell, Barton, and also in the Isle of Wight, it attains a thickness of 300 feet. The Barton beds have yielded 121 genera and 345 species, 309 of which are Mollusca. [*Monomyaria* $\frac{7}{13}$, *Dimyaria* $\frac{29}{100}$, and *Gasteropoda* $\frac{60}{196} = \frac{121}{345}$.]

[1] First defined by Professor Prestwich in 1847.

PLATE XXXI.

UPPER EOCENE FOSSILS.

1. *Paludina orbicularis.* Upper Eocene, Bembridge Limestone. Isle of Wight.
2. *Helix occlusa* (Edw.) Upper Eocene. Sconce and Headon.
3. *Rissoa Chastellii* (Nyst.) Upper Eocene. Hempstead, Isle of Wight.
4. *Paludina lenta* (Brander). Upper Eocene. White Cliff, Hempstead. Middle Eocene. Hordwell.
5. *Cerithium elegans* (Desh.) Upper Eocene. Hempstead Cliff, Isle of Wight.
6. *Cerithium plicatum* (Lam.) Upper Eocene. Hempstead.
7. *Bulimus ellipticus* (Sow.) Upper Eocene. Bembridge Limestone. Isle of Wight. Half natural size.
8. *Planorbis discus* (Edw.) Upper Eocene, Bembridge Limestone. Isle of Wight.
9. *Cyrena semistriata* (Desh.) Upper Eocene. Hempstead Cliff, Isle of Wight.
10. *Corbula pisum* (Sow.) Upper Eocene. Hempstead Cliff, Isle of Wight.
11. *Chara tuberculata* (Seed-Vessel). Bembridge Limestone. Isle of Wight.

PLATE XXXI.

UPPER EOCENE FOSSILS.

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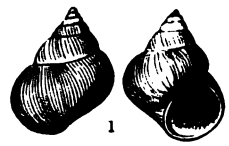

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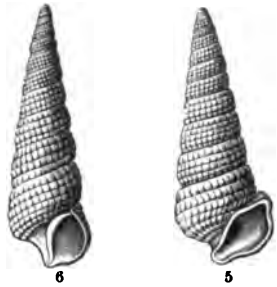

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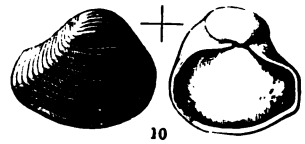

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Fauna.—The Barton Clay does not occur in the London Basin, but forms an important feature in the Hampshire or southern area, where it is well known through the richness and abundance of its fossils. The lower part of the Barton Clay is represented in Alum Bay by clays with crushed *Turritella*, *Rostellaria rimosa*, *Voluta luctatrix*, *V. athleta*, *Fusus longævus*, *Conus dormitor*, &c. The upper portion is composed of grey clays and hard calcareous grit with *Corbula pisum*, *Pectunculus deletus*, and *Actæon*, sp.; *Nummulina variolaria*, *Calyptræa trochiformis*, *Typhis pungens*, *Pecten reconditus*, *Phorus agglutinans*, *Murex asper*, *Sanguinolaria compressa*, *Fusus pyrus*, and *Crassatella sulcata*. The whole fauna of the Barton beds in the Isle of Wight numbers 49 genera and 90 species, of which 42 genera and 82 species are Mollusca.

The relationship between the Barton and Headon series is through the Mollusca, illustrated in the group *Monomyaria* by $\frac{1}{7}$ [three species passing to the Headon group, viz., *Anomia tenuistriata*, *Avicula media*, and *Ostrea flabellula*, *or ventrilabrum*], and in the group *Dimyaria* by $\frac{3}{100}$ species—17 genera and 29 species being common to the two horizons.

The Gasteropoda, which number $\frac{60}{106}$ species, are connected with the Headon beds through $\frac{2}{60}$ species, so that out of the Barton Molluscan Fauna of 96 genera and 310 species, $\frac{5}{85}$ pass up to the Oligocene or Headon or Fluvio-marine series, and only $\frac{1}{6}$ pass beyond or into the Bembridge limestones and marls. They are: *Corbula pisum*, *Cytherea* (*Venus*) *incrassata*, *Mytilus affinis*, and *Nucula similis*.

The intermediate Upper Bagshot sands are unfossiliferous, therefore have no palæontological value. They are from 250 to 300 feet thick, and may be studied on the Chobham and Frimley ridges, also at Bagshot and Sandhurst. In the Isle of Wight at Headon Hill they attain a thickness of 200 feet, and are known as the Headon Hill sands. These sands are of considerable economic value, being, from their whiteness and purity, well suited for glass-manufacture.

CHAPTER LIII.

OLIGOCENE STRATA.

Description and History.—The name "*Oligocene*" was proposed by Professor Beyrich in 1855[1] to include an extensive group of strata distinct from the underlying Eocene beds of France and Belgium, and apparently certain beds in the Isle of Wight, and the mainland in Hampshire.[2] Oligocene strata, however, are but sparingly distributed

[1] "Ueber den Zusammenhang der Norddeutschen Tertiärbildungen, zur Erläuterung einer Geologischen Uebersichtskarte," Abhandl., der K. Akad. der Wissenschaften zu Berlin. 1855.

[2] This name has been accepted wherever its upper member is known in Germany. The London Clay and Lower Tertiaries now constitute the Lower Eocene; the Bracklesham series, the Middle; the Barton Clay, the Upper Eocene. The

in Britain. They consist partly of terrestrial, freshwater, and brackish, and partly of marine beds, clearly indicating great instability of the land, and considerable oscillation of level, over a very considerable portion of the European area (N. Germany, Austria, Poland, France, and Belgium, &c.) Many strata classed by Lyell as older Miocene are now regarded as coming under the term "Oligocene." These variable—and at the time of deposition, owing to the repeated changes of level between land and water, ever-varying—deposits present none of the massive deeper-water characters which illustrate many of the Eocene sub-divisions. There would appear to have been in the heart of Europe extensive lake-basins, converted into such through elevation of the sea-floor over extensive areas: in these basins thick lacustrine deposits were accumulated. Among the Bivalve Mollusca are the ordinary marine forms—*Pecten*, *Ostrea*, *Nucula*, and *Cardium*, Gasteropoda, with *Planorbis* and *Melania*; Freshwater and Estuarine forms—*Voluta*, *Fusus*, *Conus*, *Cerithium*, *Murex*, &c. According to A. Milne Edwards, between 60 and 70 species of Birds have been found in the lacustrine beds of the Department of the Allier.[1] Many of these birds are no longer met with in the region north of the Mediterranean. M. Gaudry, in his *Enchainements du Monde Animal*, pp. 4–6 (Introduction), gives the chronological sequences of appearances and disappearances of the Eocene, Miocene, and Oligocene Fauna.

Range and Position.—It is doubtful, in the present condition of our knowledge of the strata between the Barton and Bembridge beds, whether we may safely state that the Oligocene group can be accepted for Britain. It can but be sparingly developed; its place would be between the top of the Barton beds and the Miocene; and, according to Von Kœnen, 46 species corresponding with the Lower Oligocene of Germany occur at Brockenhurst; 17 of these are Barton forms.[2] The Middle Oligocene occupies an extensive surface on the Continent, as evidenced by the *Sables de Fontainebleau* in France; and the Mayence Basin, with its Rupelmonde clay, or clay with septaria. Eastward in Germany, near Brunswick, Magdeburg, and Berlin, in Mecklenburg, and north of Stettin, the Middle Oligocene is largely developed, consisting of many hundred feet of yellow ferruginous sands.

Much importance is attached to the marine series forming the middle division of the Headon beds, thus serving as a basis of correlation between the English strata and their equivalents on the Continent. This series occurs at Colwell Bay, Headon Hill, and Whitecliff Bay, in the Isle of Wight; also at Brockenhurst, in the

Système Tongrien inférieur represents the Lower Oligocene, and the *Système Rupélien* the Middle Oligocene. The Lower Oligocene is well developed with a true marine fauna in Belgium, near Tongres (north of Liége), and in the north of Germany between Magdeburg, Bernburg, Egeln, and Helmstädt, and contains 700 species of Mollusca.

[1] "Oiseaux Fossiles," 4to. Also W. Boyd-Dawkins ("Early Man in Britain," &c., pp. 54, 55), who enumerates many genera.

[2] "On the Correlation of the Oligocene Deposits of Belgium, North Germany, and the South of England," by Herr Adolf von Kœnen, Q. J. Geol. Soc., vol. xx. pp. 97–102.

New Forest. These Middle Headon beds have yielded 220 species of Mollusca[1] and many corals (7 genera and 14 species) from Brockenhurst. Some of the forms named by Messrs. Tawney and Keeping in their paper[2] are common to the Lower Oligocene of France and Germany.

The top of the Fluvio-Marine series in the Isle of Wight has been partly removed by denudation, so that much evidence has disappeared. The Brockenhurst bed at Whitecliff Bay has yielded 39 genera and 50 species (45 mollusca and 5 corals). At the base of the Fluvio-Marine series occurs the rich marine deposit of the Barton clay. No less than 300 species of Mollusca have been determined from this formation. The Barton Clay is represented in the Paris basin by the "*Sables Mayennes*" or "*Sables de Beauchamp*," and in Belgium by the "*Système Lækénien*" of Dumont.

Lying upon the Barton Clay there occurs a great series of estuarine strata, in places attaining a thickness of 400 feet, which is succeeded by the *second* marine fauna. This second marine series is distinct from that of the Barton Clay, from which it differs, and it occurs at many points upon the Continent. The Montmartre and other freshwater beds appear at this horizon to the exclusion of the marine beds.

Bovey-Tracey Beds.—The Bovey-Tracey plant-bearing strata have been considered to be of Miocene age. By some authors the Bovey beds are regarded as equivalents of the Oligocene beds of the Continent. The strata, which are between 200 and 300 feet thick, are composed of sand, clay, and Lignite beds, deposited at the southern side or foot of the Granite of Dartmoor, between it and the Upper Greensand of Haldon, &c. Professor Heer places the flora in this group of strata on the same geological horizon with a portion of the Molasse or Oligocene (Lower Miocene) of Switzerland.[3]

Plants.—Among the plants are many ferns—*Lastræca Stiriaca* and *L. Bunburyi*, *Pecopteris lignitum*, besides *Nyssa Europæa*, *N. lævigata*, *Palmacites Dæmonorops*, *Pterocarya denticulata*, &c., *Rhamnites lanceolatus*, *Sequoia Couttsiæ*, *Vitis Britannica*, *Folliculites minutulus*, *Ficus eucalyptoides*, *Eucalyptus oceanicus*, *Echitonium cuspidatum*, *Cinnamomum Scheuchzeri*, *Andromeda vaccinifolia*, and *Anona Devonica*.

The matted remains of *Sequoia Couttsiæ* form one of the Lignite beds, and the entire flora appears to infer a sub-tropical climate;[4] whatever may be the true age of this flora, the new reading would place the beds in the Oligocene as probable equivalents of the brown coal and Molasse of the Continent.

[1] Eighty-six of these are MS. names, the species occurring in the Edwards' collection in the British Museum; 22 of the 220 species occur in the Upper Bagshot beds. Seven of the 22 species are Estuarine or Brackish water forms.

[2] On the beds at Headon Hill and Colwell Bay, in the Isle of Wight; Q. Jour. Geol. Soc., vol. xxxvii. pp. 115–120.

[3] Heer has described the plant-remains of this basin in the Phil. Transactions of the Royal Soc. for 1862, the geology of the area being described at the same time by Mr. Pengelly, F.R.S.

[4] Mr. J. Starkie Gardner believes that the Bovey flora is of the same age or on the same horizon as the Bournemouth beds (Middle Eocene or Bagshot beds). Whether the Leaf beds or Volcanic rocks of the North-West of Scotland and Ireland can be relegated to the Eocene period is doubtful.

Analysis of the Oligocene or Fluvio-Marine Strata of the Isle of Wight.

The accompanying extended tables present an analysis of the Oligocene or Fluvio-Marine Series of the Isle of Wight, arranged in descending order from the Hempstead beds to the Lower Headon. The characteristic species in each subdivision are given in the second table.

			Ft.	in.
Oligocene.	[1] Hempstead beds $\frac{2}{4}\frac{4}{5}$	1. *Corbula* beds	9	6
		2. Upper Freshwater and Estuary marls	30	0
		3. Middle Freshwater and Estuary marls	50	0
		4. Lower Freshwater and Estuary marls	70	0
	Bembridge beds $\frac{3}{5}\frac{0}{5}$	1. Bembridge marls	62	0
		2. Bembridge limestone	12–25	0
	Osborne and St. Aplens beds $\frac{1}{1}\frac{2}{4}$	Clays, marls, sands, and limestones	70	0
	Headon beds $\frac{1}{1}\frac{1}{7}\frac{1}{3}$	1. Headon beds (Upper) — Marine and Freshwater.		
		2. Headon beds (Middle)—Brackish-water and Marine.		
		3. Headon beds (Lower)—Fresh and Brackish water	135–175	0

TABLE CIII.—*Oligocene Fauna through the Headon, Osborne, Bembridge, and Hempstead Groups.*

			Ft.	in.
Hempstead beds. 160 ft.	*Corbula* beds (marine) 20 ft.	1. Brown and greenish nodular Clays and shelly beds—(*Corbula Vectensis, C. pisum, Cyrena semistriata, Cerithium plicatum. C. subcostellatum, Ostrea callifera, Natica labellata, Cyprids*, &c.)	9	6
	Upper freshwater and estuary marls. 30 ft.	2. *Upper Freshwater and Estuary* Marls—(*Cerithium plicatum, Corbula vectensis, Cerithium elegans, Cyrena semistriata, Hydrobia pupa, Rissoa Chastelli, Melania Nystii* (*inflata*), *Unio Austeni*, &c. *Planorbis lens, P. vortex*)	30	0
	Middle freshwater and estuary marls. 50 ft.	3. Middle Freshwater and Estuary Marls—(*Cyrena semistriata, Paludina lenta, Cerithium Sedgwickii, Melania fasciata, Panopæa minor, P. Gibbsii*, &c.)	50	0
	Lower freshwater and estuary marls. 70 ft.	4. Lower Freshwater and Estuary Marls—*Melania muricata, Melanopsis carinata, Euchilus* (*Hydrobia*) *Chastelli, Modiola Prestwichii, Paludina lenta, Cyrena semistriata, Chara* (*Gyrogonites*), and other aquatic and *Terrestrial Plants—Entomostraca, Planorbis obtusus*	70	0

[1] The figures refer to the number of genera and species occurring in the several groups; thus the Headon beds have yielded 111 genera and 278 species, &c. &c.

TABLE CIII.—(*Continued.*)

Bembridge Beds. Whitecliff Bay, St. Helen's, Yarmouth, Newtown, &c.	1. Bembridge Marls, Upper or Argillaceous series—(*Potamadis* (*Melania*) *turritissimus, Cytherea incrassata, Melanopsis carinata, Cerithium mutabile, Cyrena pulchra, C. semistriata, Ostrea vectensis*)	62 0
	2. Bembridge Limestone, Lower or Calcareous series—(*Limnæa longiscata, Hyalinia* (*Helix*) *d'Urbani, Helix occlusa, Planorbis obtusus, P. oligyratus, Melania excavata, Cyclotus cinctus, Amphidromus* (*Bulimus*) *ellipticus, Cyclostoma mumia,* and *Achatina*) .	12–205 0
Osborne or St. Helen's Beds. Whitecliff Bay, St. Helen's and Ryde, Cliff End Sconce.	Clays, marls, sands, and limestones—(*Chara Lyellii, Cyrena obovata, Melania costata, Melanopsis brevis, M. carinata,* and many species of *Planorbis* (*P. lens,* &c.), *Paludina lenta,* &c. &c., *Limnæa longiscata, Potamomya plana, Achatina costellata*) . .	70 0
Upper Headon clays and limestones.	Headon Beds.—Upper. Uppermost Marls and Clays and thick beds of Limestone with *Cerithium lepidum, Potamomya plana, Cyrena obovata, Potamides margaritaceus* (Sow.), *Melania muricata, Paludina lenta, Nystia* (*Bulimus*) *politus,* &c. . . .	
Middle Headon brackish-water and marine series.	2. Middle. Intermarine, and containing brackish-water and marine fossils—*Cytherea* (*Venus*) *incrassata, Nucula deltoidea, Natica depressa, Buccinum labiatum, Potamides ventricosus, P. concavus, Ostrea flabellula, O. callifera, Murex sexdentatus, Pleurotoma Headonensis, Ancillaria subulata, Cancellaria muricata, Cerithium concavum* . .	
Lower Headon fresh and brackish-water series.	3. Lower. Fresh and Brackish-water beds—the fossils in this division are identical with those of the upper—*Cyrena cycladiformis, Unio Solandri, Helix Headonensis, Planorbis euomphalus, P. rotundatus, P. lens, Limnæa longiscata, Paludina lenta, Potamomya plana* and *Potamides cinctus* abound in the brackish-water beds, and *Cytherea* (*Venus*) *incrassata* in the marine bands .	135–175 0

Oligocene Strata on the European Continent.

Paris Basin.—A complete upward passage is traceable in the Paris Basin from the Eocene into the Oligocene. Dolfuss describes three groups in nine subdivisions.[1]

[1] Dolfuss: Bull. Soc. Géol. France, 3e sér. vol. vi. p. 293. 1878.

Upper Oligocene.		1. Meulières de Montmorency—Siliceous cellular fossiliferous freshwater Limestone. *Limnæa, Bythinia, Valvata, Planorbis.* 2. Grès de Fontainebleau sand and hard siliceous sandstones. *Cytherea (Venus) incrassata, Lucina Heberti.*
Middle Oligocene.	Sable d'Etampes.	3. Sables de Fontenay, Jeurre et Marigny, thick yellow ferruginous sands. 4. Marls—Marine Molasse—*Ostrea longirostris* at the base, *O. cyathula* above, and *Corbula sub-pisum* at the top. 5. Calcaire de Brie. 6. Green marls comprising an upper non-fossiliferous Clay, and a lower group of fossiliferous laminated marls. *Cerithium plicatum, Psammobia plana* and *Cyrena.*
Lower Oligocene.	Lacustrine gypseous group.	7. White marls with *Limnæa strigosa, Planorbis planulatus.* 8. Supra-gypseous blue marls with few fossils. 9. Lacustrine gypsum—The chief gypsum bed of the Paris basin, saccharoid, containing skeletons and bones of mammalia, wood, and terrestrial shells. *Helix, Cyclostoma,* &c.

Belgium.—The Belgian Oligocene differs from that of France, both as regards succession and organic remains, and has therefore received a different nomenclature;[1] only a Middle and Lower group occur, the upper being absent. Their classification is as follows:—

Upper			Wanting,
Middle.	Rupelian.	Marine.	White sands of Bolderberg [Bolderien], Clay of Boom, and *nucula* Clay of Bergh —*Nucula Compta* (*Leda Lyelliana*) *Corbula sub-pisum.* Upwards of 140 species of fossils.
		Fluvio-Marine.	*Cerithium* sands of Vieux Jonc [*Klein Spauwen*] and *Pectunculus* sands of Bergh. Henis Clay — Fluvio-marine fossils. (*Cerithium, Melania, Bythinia, Cyrena*).
Lower.	Tongrian.	Marine.	Sands of Neerepen. Sands of Grimmertingen. The Tongrian deposits contain a marine fauna = the Egeln beds of Germany.

Germany.—[2] The oligocene groups are well developed in Northern Germany, both in their Marine and Freshwater types. The term "*Oligocene*" was proposed by Beyrich from the physical characters of the beds in Northern Germany. They occupy large, more or less detached areas or basins, having local lithological and palæontological variations. The following general subdivisions have been established:—

[1] Mourlon: "Géologie de la Belgique," vol. i. 8vo. Brux. 1880.

[2] Beyrich: Monatsbericht, Akad. Berlin. 1854, p. 640, 1858, p. 51. Credner: Elemente der Geologie, 3rd edition. 8vo., Leipzig, 1876. A. von Könen: "Ueber die Parallelisirung des Norddeutschen, Englischen, und Französischen Oligocäns, 8vo., Berlin. 1867.

Lower Oligocene.	"Egeln marine beds—(*Ostrea ventilabrum*, *Arca appendiculata*, *Cardita Dunkeri*, *Cardium Hausmanni*, *Cytherea Solandri*, *Cerithium lævum*, *Pleurotoma Beyrichi*, *Voluta decora*, &c., and corals of the genera Turbinolia, Balanophyllia, Caryophyllia, Cyathina). Amber Beds of Königsberg.—Glauconite sands with abundant pieces of amber. The sands contain Lower Oligocene marine Mollusca. Lower Brown-Coal.—"Sands, sandstone conglomerates and clays with interstratified varieties of brown coal (pitch coal, earthy lignite, paper coal, wax coal, &c.) The flora of the brown coal is largely composed of the Coniferæ (*Taxites*, *Taxoxylon*, *Cupressinoxylon*, *Sequoia*, &c.), also *Quercus*, *Laurus*, *Cinnamomum*, *Magnolia*, *Ficus*, *Sassafras*, *Alnus*, *Acer*, *Juglans*, *Betula* and Palms (*Sabal* and *Flabellaria*.) The general aspect of this flora most resembles that of the southern States of North America.
Middle Oligocene.	Stettin-sand—and Septaria Clay (*Septarienthon*) with an abundant marine fauna—*Pecten*, *Leda*, *Axinus*, *Fusus*, &c. "These beds are widely distributed in North Germany, and are the only representatives of the Middle Oligocene deposits.
Upper Oligocene.	Brown-coal deposits of the Lower Rhine, &c., with flora allied to that of sub-tropical N. America. (*Acer*, *Cinnamomum*, *Juglans*, *Cupressinoxylon*, *Nyssa*, *Pinites*), &c. *Terebratula grandis*, and *Pecten Janus*, occur in some of the marine beds."

A. GEIKIE.

Switzerland.[1]—The Oligocene strata attain a thickness of 6000 feet in Switzerland. They form part of the great deposits termed Molasse.[2] The lower portions of this deposit are now placed on the same parallel with the northern Oligocenes, and consist of the following sub-divisions:—

a. Aquitanian Stage.—"Lower Brown-Coal or Red Molasse, the most massive member of the *Molasse*, consisting of Red sandstones, marls, and conglomerates (Nägelfluhe),[3] resting upon variegated red marls. It contains seams of lignite, and a vast abundance of terrestrial vegetation."

b. Tongrian Stage.—"Lower marine *Molasse*—sandstone containing marine and brackish-water shells. *Ostrea cyathula* (*a*), *O. longirostris*, *Cyrena semistriata* (*b*), *Pectunculus obovatus*, *Cerithium plicatum* (*c*)" (*a*, *b*, and *c* are British species). Most of these strata are of lacustrine origin.

Central France.—The heart or centre of France must have held one or more extensive sheets of fresh water. In these basins in the Limagne d'Auvergne a series of marls and limestones 1500 feet thick

[1] Heer, Die Urwelt der Schweiz. 8vo. Zurich, 1865.

[2] A term used for the soft arenaceous beds which constitute the Middle Tertiaries of Switzerland. The Molasse is thickly developed in the great Swiss valley, and also spreads over large tracts in France. The Molasse comprises three divisions: an upper freshwater, a middle marine, and a lower freshwater, which is probably of older Miocene age—but the Molasse as a whole was formerly considered to be entirely Miocene.

[3] A Swiss term for a soft arenaceo-calcareous conglomerate occurring among the Miocene (Oligocene) Tertiaries of the Alps, it attains the thickness of 6000 or 8000 feet at the Righi near Lucerne and in the spur near Woren, and is so named from the enclosed pebbles appearing like nail-heads (*Fluhe*, *Nägel*) in the mass; it is termed *Sompholite* or nail-stone by Brongniart.

were deposited, from which has been obtained a large Mammalia fauna—including Palæotherium. This water basin occupied the site of the numerous cones and *puys* so conspicuous on the Plateau of Auvergne, and, as suggested by .Geikie, appears to have been destroyed by volcanic eruptions which poured out the great sheets of lava over that remarkable area.

Vienna Basin.[1]—Later Tertiary deposits, classed as "*Neogene*,"[2] occupy the area of the Vienna Basin. The "*Aquitanian stage*," composed of marls and sandstones, lies at the bottom of the deposits, in which seams of brown-coal occasionally occur and freshwater beds, with intercalations of marine strata. These marine beds contain well-known British species of Mollusca, *Cerithium plicatum*, *C. margaritaceum*, &c. The brackish and freshwater beds yield *Melania Escheri* and *Cyrena lignitaria*. Among the Vertebrata are *Mastodon angustidens*, *M. tapiroides*, *Rhinoceros sansaniensis*, *Amphicyon intermedius*—the oldest known member and representative of the Ursidæ—and *Anchitherium*, nearly allied to the *Palæotherium*.

Headon Hill Fluvio-marine Group, Prestwich, 1846. *Headon Series, Forbes*, 1853.[3]

Above the Barton clay in the Isle of Wight occur about 100 feet of white and yellow sand, without organic remains, in beds much less inclined than those already noticed. These Headon sands are the base of the well-known freshwater marls and limestones of Headon Hill. They are in two groups, "upper" and "lower," parted by layers of purple and green marls, full of estuarine and marine shells, distinct from those of the subjacent tertiary clays. Among them are *Potamides* by myriads, *Natica*, *Neritina*, *Voluta*, *Fusus*, *Ancillaria*, *Cyclas*, *Venus*, *Cytherœa*, *Ostrea*, &c. The "lower freshwater beds," including perhaps some Headon Hill sands below, are formed in many layers of marly and sub-calcareous bands, containing *Limnœæ*, *Planorbes*, &c., with slight partings of an estuarine character. The "upper freshwater" beds are on the whole more calcareous than the lower series, their total thickness being above 70 feet.

This group is best seen at Headon Hill in Colwell and Whitecliff bays in the Isle of Wight, and the lowest members at Hordwell Cliff on the Hampshire coast. The Headon series is, upon physical grounds, clearly divisible into three groups, Lower, Middle, and Upper, each

[1] Suess: "Der Boden von Wien," 1860. Von Hauer: "Die Geologie und ihre Anwendung auf die Kenntniss der Bodenbesch. der österr-ungar. Monarchie." 8vo. Vienna, 1875.

[2] The Pliocene and Miocene Tertiaries are grouped together by some Continental geologists under this name (new-born) (*neos*, new, and *genomai*, I am formed) in contradistinction to the older Eocene strata.

[3] The Headon series was subdivided by Mr. Prestwich into Upper and Lower Headon Hill Marls and Limestones; and by Forbes into Upper, Middle, and Lower Headon beds, the Upper and Lower divisions of which are freshwater strata, and the Middle, marine. This classification is adopted in the Geological Survey Memoirs on the Isle of Wight in 1856 and 1862.

division being characterised by its own suite of fossils. The Upper series consists of marls with *Cerithium*, and freshwater and brackish water beds. The Middle are an intermarine group; and the Lower, fresh and brackish water beds, with *Cyrenæ—C. cycladiformis* being the characteristic shell.

Professor Forbes' last researches[1] satisfactorily show the occurrence at Whitecliff Bay of an Upper or Bembridge freshwater group, separated by 100 feet of strata from the Lower freshwater of Headon Hill.

The series of freshwater beds is even here not complete, there being a still higher group at Hempstead Hill, near Yarmouth.

Subdivisions:—*Upper Headon.*—These constitute the greater portion of the Upper Freshwater series. The mass of freshwater limestone in Headon Hill (Isle of Wight) belongs to this section. The beds are brackish in the upper part, abounding in *Potamomya* and *Cyrena obovata*; at Cliff End they contain *Cyrenæ* (like *C. pulchra*). *Cerithium trizonatum* occurs here abundantly, and *Bulimus politus* and *Melania muricata* are plentiful.

Middle Headon. "*The Headon inter-marine or Upper marine formation.*"—At Headon Hill these deposits were accumulated under brackish-water conditions; for, although *Ostrea*, *Cytherea incrassata*, *Nucula deltoidea*, *Natica depressa*, *Buccinum labiatum*, and other marine shells are common, the upper and lower beds abound in *Cerithium ventricosum*, *Cerithium concavum*, *Cerithium pseudocinctum*, *Neritina concava*, and *Nematura*, &c., which are brackish or estuarine. A short distance further north, in Colwell Bay, the upper and lower beds contain brackish-water shells; *but the central part assumes a distinctly marine character. Ostrea velata* is a characteristic species, and occurs with numerous marine genera, many of which are of Barton types. This central part is known as the "*Venus bed*," from the presence of *Cytherea* (*Venus*) *incrassata*. The marine character of the *Middle Headon beds* is still more strongly marked at Whitecliff Bay, where 22 genera occur. The lower portion of this series contains many Brockenhurst species, but at Colwell Bay we *have no evidence of characteristic species from this last horizon*, or in *the western side of the island.*

Lower Headon, fresh and brackish-water series. These beds are 70 feet thick in Totland Bay, and 40 feet thick in Whitecliff Bay. They consist of fresh and brackish-water beds, abounding in fossils resembling those of the upper division. *Unio Solandri* and *Cyrena cycladiformis* occur here, and are characteristic.

At Headon Hill the thick bed of limestone in the Upper Headon is conspicuous in the cliffs, but it thins out rapidly towards the north, and disappears in an easterly direction. Two hundred and seventy-eight species have been obtained from the Headon series; 227 Mollusca, 3 Crustacea, 6 Annelids, and 5 plants, land, freshwater, and marine; the fossils of the Headon fluvio-marine series are $\frac{2}{7}\frac{3}{4}$ Gasteropoda, $\frac{1}{2}\frac{5}{5}$ Pelecypoda; Polycipes 1, Balanus 1, Crustacea $\frac{5}{9}$, Plantæ $\frac{2}{2}$, Fish $\frac{2}{3}$.

The St. Helen's Beds, or Osborne and St. Helen's, Forbes, 1853.

These lie between the *Upper Headon series* proper, containing *Potamomya* and the Bembridge limestones. They are of freshwater and brackish-water origin, about 100 feet thick.

[1] Mem. Geol. Surv. of Great Britain on the Tertiary Fluvio-marine Formation of the Isle of Wight, 1856.

Paludinæ (*P. lenta*), *Melaniæ* (*M. costata*, *M. excavata*), *Melanopsis brevis*, and *M. carinata* occur; *Chara Lyellii* is the Gyrogonite of this limestone band, which divides the Upper or Nettlestone beds from the Lower or St. Helen's sands.

Between the Bembridge limestone and the brackish-water beds with *Potamomyæ*, that terminate the Headon beds, intervenes a great series of strata, which, on account of their mineralogical and palæontological peculiarities, deserve and hold an intermediate position between the Middle and Upper Eocene strata.

Osborne Series in Whitecliff Bay.—Thickness 100 feet. Dark-red, bright-red, and variegated clays, containing *Helix occlusa*, *Planorbis discus*, and *Limnæa longiscata*.

Osborne Series between St. Helen's and Ryde.—Between Brading Harbour and Ryde sections occur, and on shore are seen the rocky ledges below Seafield, and from St. Helen's to Nettlestone. At Watchhouse Point, below St. Helen's, the Bembridge limestone forms an extensive arch, so as to bring the lower beds into view. The base of the Osborne beds is not here exposed. The Nettlestone division of the Osborne series is seen opposite the Priory, through an up-throw fault. The succession of the series in *descending order* is as follows:—

1. **St. Helen's Sands**—

	Ft.	in.
a. Immediately below the Bembridge limestone there occurs a band of carbonaceous clay	1	6
b. Pale-greenish and yellowish sands, marls, and comminuted shells, with *Melania excavata*	8	0
c. Yellowish-green and white sands, with lenticular siliceous concretions and spongeoid bodies	14	0
d. Greenish-yellow irregular and concretionary sandstone, with fucoidal bodies	3	0
e. Laminated white sands, showing current marks. Contain *Limnæa longiscata*, *L. peregeri*? *Planorbis obtusus* and *Melania excavata* in the form of casts	3	0
f. White sandy clay with broken *Cyrenæ*	2	0
g. Greenish-blue clay, seen at low-water, with *Melania* and *Cyrenæ*	8	0

2. **Nettlestone Grits**—

	Ft.	in.
h. Soft yellow limestone, with minute confervoidal cavities. *Limnæa longiscata*, *Hydrobia*, *Chara Lyellii* occur	2	0
i. Yellow and white marly clays, with argillo-calcareous nodules, in which occurs *Melania excavata*	4	0
k. Freestone, with siliceous concretions—*Melania excavata*, *Paludina lenta*, *Hydrobia*, *Melanopsis brevis*, *M. carinata*, *Planorbis rotundatus*, *Limnæa longiscata*, &c.	8	0
l. Soft white sandstone, with concretionary bands, containing *Limnæa longiscata* and *Unio*	4	0
m. Shelly sandstones, with angular flints *n*. Soft calcareous stone, *Paludina lenta* *o*. Sandstone flags, with ripple-marks	1	6

Osborne Series between Ryde and Cowes.—The green and red marls and clays comprising these beds occur in the cliffs, and on the shore west of Wootton Creek, and are overlaid by the Bembridge beds. *Melania excavata*, *M. costata*, *Melanopsis carinata*, and *M. brevis*, with *Paludinæ* and *Hydrobiæ*, and nucules of

Chara abound. Landslips and cultivation obscure the stratigraphy and general geology of the slopes. The beds on the western side of the Osborne belong to the Lower or Nettlestone division, whilst to the east occur the members of the higher or St. Helen's group.

Osborne Series at Cliff End, near Sconce.—The beds rise from below the Sconce limestone, and crop out by the first chine in Colwell Bay, beyond Cliff End. Total thickness about 60 feet. The characteristic fossils are—*Melania excavata, M. costata, Melanopsis brevis, M. carinata, Planorbis obtusus, P. euomphalus, P. platystoma, Paludina lenta, P. globuloides, Achatina costellata, Cyrena obovata, Potamomya plana.* The entire fauna numbers only 20 genera and 32 species.

Bembridge Beds, Forbes, 1853–1856.

Of the fluvio-marine strata of the Isle of Wight, the *Bembridge* series is by far the most constant in lithological characters. The lower part is calcareous (marine and freshwater); the upper part consists of alternations of marls and laminated clays, mostly of freshwater origin, about 80 feet thick, and divided into an upper and a lower Bembridge marl, the Bembridge oyster-bed, and the Bembridge limestone.

By far the larger portion of the Tertiary surface of the Isle of Wight is occupied by the Bembridge beds, which overlie the Headon series, or Headon Hill group. Stratigraphically, they possess high interest, being representatives of extensive Continental formations, through which we are enabled to correlate, or throw considerable light on the classification of, foreign Tertiary strata. Through these Bembridge strata we acquire much information respecting the terrestrial fauna of our own area during the later portion of the Eocene epoch.

1. Palæontologically, the Upper Bembridge marls are characterised by the abundance of *Melania turritissima*. These marls, containing also *Cyrena pulchra*, are finely shown in Whitecliff Bay, on the shore at Hempstead, and at Thorness.

2. The upper beds of the *second group* are exposed in the clearest manner through fine sections at the same places, and also at or near Brading Harbour, below St. Helen's. Remains of *Trionyx*, or the freshwater tortoise, with *Cerithium variabile*, and *Cyrena pulchra*, characterise these beds.

3. The *third group*, or the Bembridge oyster-beds, forms "a narrow but constant band between the marls and the limestones. Marine conditions set in here, characterised by the abundance of *Ostrea vectensis, Nucula similis, Cytherea incrassata, Mytilus*, and *Cerithium*." At Whitecliff Bay and Brading Harbour this group may be advantageously studied.

4. The *fourth subdivision*, or Bembridge limestone, includes those beds exhibited at Binsted, Cowes, Calbourn, and Sconce (but not the limestones of the Headon series). The Binsted Quarries belong to this group, and yield *Palæotherium, Anoplotherium*, with many land shells.

This remarkable limestone in Whitecliff Bay is conspicuous in the

cliffs; it is also the marked feature at Bembridge ledge. When closely inspected it is found to be composed of a number of distinct beds or strata. In ascending order we readily recognise seven divisions, each characterised by freshwater mollusca and some few land plants:—

Bed No. 1. Concretionary limestone containing the freshwater plant *Chara tuberculata*, with *Limnæa longiscata*.
„ 2. Greenish marly clay, *Lim. longiscata* and *Planorbis*.
„ 3. Compact creamy-yellow limestone, *Lim. longiscata* and *Planorbis oligyratus*.
„ 4. Pale marly limestone, compact in places, full of *Paludina globuloides*, *Lim. longiscata*, *Hydrobia*, and *Cyclostoma mumia*.
„ 5. Greenish-white limestone, concretionary and fossiliferous, containing *Lim. longiscata*, *Planorbis discus*, *P. rotundatus*, *P. Sowerbyi*, *P. obtusus*, *Helix occlusa*, *Helix labryrinthica*.
„ 6. Crumbly white marl, with globular concretions, *Chara tuberculata*, *Planorbis obtusus*.
„ 7. A bed similar to 6, with *Planorbis discus*.
The whole about 25 feet thick.

The strata along the coast and section are in many places finely shown, and present peculiarities not elsewhere seen in the island.

Hempstead Series, Forbes, 1853–1856.[1]

East of Yarmouth is Hempstead Cliff, with its crest or summit about 210 feet above the sea. It is formed entirely of marls and clays, capped with gravels; the strata composing the structure of the cliff are slightly recurved and trough-shaped, arising from the position of a synclinal axis which crosses the Hill near the summit; the marls and clays forming the base of the cliff belong to the Bembridge series. The thickness of the Hempstead series is about 170 feet, and the beds comprising them admit of being grouped into 4 distinct sections. These are the latest and highest of the Tertiary strata in the Isle of Wight, and occur in a very limited extent, being confined, so far as we know, to Hempstead Hill between Yarmouth and Newtown, and a tract inland near Newport, called Parkhurst Forest.

1. The *Corbula beds*—of marine origin, 20 feet thick, and the highest member of the Hempstead series.
2. Upper Freshwater and Estuary Marls—crowded with *Cerithium plicatum*, separated from the succeeding Freshwater and Estuary Marls. 30 feet.
3. The Middle Freshwater and Estuary Marls—distinguished by the abundance of *Melania fasciata*. 50 feet.
4. The Lower Freshwater and Estuary Marls—containing *Melania muricata* and *Melanopis carinata*, excluding the Black Band, at the base of the series. Thickness about 70 feet.

Characteristic Fossils.—The characteristic fossils of the Hempstead group are:—

[1] See Mem. of the Geol. Survey of Great Britain, "Tertiary Fluvio-Marine Formation of the Isle of Wight," by Edward Forbes, F.R.S., pp. 37–49, for complete description of the Hempstead series in its 4 sub-divisions.

MARINE.—*Natica labellata, Fusus Edwardsii, Voluta Rathieri, Cuma Charlesworthii, Murex Forbesii—Cerithium plicatum, C. elegans, C. mutabile, C. pseudocinctum* and *C. Sedgwickii, Melania fasciata, M. muricata, Ostrea callifera, Modiola Prestwichii, Corbula pisum, C. Vectensis, Mya minor, Cytherea Lyellii.*

BRACKISH-WATER.—*Melanopsis carinata, Paludina lenta, Rissoa Chastellii, Neritina tristis.*

FRESHWATER.—*Unio Austenii, U. Gibbsii, Cyclas Bristovii.*

TERRESTRIAL.—*Hyopotamus bovinus, H. vectianus.*

TABLE CIV.—*Organic Remains of the Eocene Strata.*

See Plates No. XXIX., XXX., and XXXI. for some characteristic Eocene species.

PLANTÆ.

CRYPTOGAMIA.

Filices.

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Adiantum	1	...	1	...	...
Anemia	1	...	1	...	...
Asplenites	1	...	1	...	...
Chrysodium	1	...	1	...	...
Filicites	1	...	...	...	1
Goniopteris	1	...	1	...	...
Glossochlamys	1	...	1	...	...
Gleichenia	1	...	1	...	...
Hewardia	1	...	1	...	...
Meniphyllum	1	...	1	...	..
Lastræa	2	...	...	...	2
Lygodium	1	...	1	...	...
Phegopteris	2	...	2	...	1
Rhymatodes	...	...	...	...	...
Pteris	4	1	2	...	1
Podoloma	2	...	2	...	...
Lycopodites	2	1	1	...	...
Onoclea	1	...	...	...	1
Pecopteris	1	...	...	...	1
Lastræa	2	...	...	...	2
Marattia	1	...	1	...	...
Osmunda	1	...	1	...	...
Osmundites	1	1	...	...	...
Woodwardia	1	...	1	...	...
24	31	3	20		9

CHARACEÆ.

Chara	1	...	...	1	...

PHANEROGAMIA.

Palmæ.

Elais	...	...	...	...	...
Flabellaria	1	...	...	1	...
Sabal	2	1	1	...	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Iarteria	1	...	1	...	...
Musa	1	1	...	...	...
Palmacites	1	...	...	...	1
6	6	2	2	2	1
Coniferæ (Gymnospermæ). Monochlamydeæ.					
Araucaria	...	...	...	...	...
Abies	1	1	...	...	...
Callitrites	5	5	...	...	...
Frenellites	4	4	...	...	...
Cupressus	1	...	1	...	...
Cupressites	1	...	...	...	1
Ginkgo	...	...	...	...	...
Librocedrus	1	1	...	...	...
Peuce	1	...	...	...	1
Pinites	3	2	1	...	...
Podocarpus	1	...	...	...	1
Salisburia	...	...	...	...	...
Sequoia	4	...	1	1	3
Solenostrobus	5	5	...	...	...
Taxites	2	...	1	...	1
Taxodium	2	...	2	...	...
16	31	18	6	1	7
Dicotyledones.					
Alnites	1	...	...	...	1
Andromeda	2	...	...	...	2
Carpolithes	10	1	1	3	7
Anona	2	...	...	...	2
Berchemia	1	...	...	...	1
Comptonia	...	...	...	...	...
Cucumites	1	1	1	...	...
Celastrus	1	...	...	...	1
Cupanoides	8	8	...	...	...
Corylus	1	...	...	...	1
Cinnamomum	3	...	...	...	3
Daphnogene	4	...	...	...	4
Dalbergia	1	1	...	...	...
Dryandra	1	...	1	...	...
Dryandroides	4	1	...	...	3
Echitonium	1	...	...	...	1
Eucalyptus	1	...	...	...	1
Eugenia	2	...	...	...	2
Faboidea	25	25	...	...	...
Ficus	8	5	1	...	3
Folliculites	3	1	2	...	1
Gardenia	1	...	...	...	1
Grevillia	2	1	1	...	...
Hightea	10	10	...	...	...
Juglans	1	...	1	...	...
Laurus	5	1	4	...	...
Leguminosites	19	18	...	...	1
Mimosites	1	1	...	...	...
Nelumbium	1	...	...	...	1
Nipadites	12	12	...	...	...

		No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Nymphæa		1	...	...	...	1
Nyssa		4	...	...	...	4
Phragmites		1	...	...	...	1
Platanites		1	...	...	...	1
Poacites		1	...	...	...	1
Porana		3	...	3	...	...
Pterocarya		1	...	...	...	1
Pterophylloides		7	7	...	...	...
Quercus		4	...	3	...	1
Rhamnus		1	...	1	...	...
Rhamnites		2	...	...	...	2
Robinia		1	1	...	...	...
Sapindus		1	...	1	...	...
Tricarpellites		7	7	...	...	...
Vaccinium		1	...	...	...	1
Vitis		3	...	...	...	3
Wetherellia		1	1	...	...	...
Xuliosprionites		2	2	...	...	...
Ziziphus		2	...	2	...	...
49		176	104	22	3	52

PROTOZOA.

Class—RHIZOPODA.

Foraminifera.

Alveolina		2	...	2	...	...
Bulimina		2	...	2	...	...
Cristellaria		2	2	...	...	...
Dentalina		5	5	...	...	...
Frondicularia		1	1	...	...	...
Globigerina		1	1	...	...	...
Globulina		1	1	...	...	...
Lituola		1	1	...	...	...
Marginulina		1	1	...	...	...
Miliola		3	3	...	...	...
Nodosaria		3	3	...	...	...
Nummulina		1	1	...	...	...
Nummulites		4	4	...	...	...
Orbitulites		1	1	...	...	...
Polymorphina		3	1	3	...	...
Pullenia		1	1	...	...	...
Pulvinulina		2	2	...	...	...
Quinqueloculina		1	...	1	...	...
Rotalia		1	1	...	...	...
Rotalina		1	...	1	...	...
Textularia		4	4	...	...	...
Triloculina		1	...	1	...	...
22		42	33	10		

CŒLENTERATA.

ALCYONARIA.

Graphularia		1	1	...	...	...
Mopsea		1	1	...	...	...
Websteria		1	1	...	...	...
3		3	3			

Class—ACTINOZOA.

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Astrocœnia	1	...	1	...	...
Axopora	3	...	3	...	...
Balanophyllia	2	...	2	...	...
Dasmia	1	1	...	...	...
Dendracis	1	...	1	...	...
Dendrophyllia	3	...	3	...	...
Diphelia	1	...	1	...	...
Leptocyathus	1	1	...	...	...
Litharea	2	...	2	...	...
Lobopsammia	1	...	1	1	...
Madrepora	3	...	3	3	...
Oculina	4	1	3	...	...
Paracyathus	5	2	3	...	...
Porites	1	...	1	...	...
Solenastræa	6	...	6	6	...
Stephanophyllia	1	1	...	...	...
Stereopsammia	1	...	1	...	...
Stylophora	2	...	2	...	...
Trochocyathus	3	3	1	...	...
Turbinolia	11	4	9	...	...
20	53	13	43	10	

CLASS—ECHINODERMATA.

ECHINOIDEA.

Cidaris	1	...	1	...	...
Cœlopleurus	1	1	...	...	...
Echinopsis	1	...	1	...	...
Echinus	1	...	1	...	...
Eupatagus	1	...	1	...	...
Hemiaster	3	3	1	...	...
Schizaster	1	1	...	...	...
Spatangus	1	...	1	...	...
8	10	5	6		

ASTEROIDEA.

Astropecten	3	3	...	...	...
Goniaster	3	3	...	...	...
Ophiura	1	1	1	...	...
3	7	7	1		

CRINOIDEA.

Bourgueticrinus	1	1	...	...	...
Cainocrinus	1	1	...	...	...
Pentacrinus	3	3	...	...	...
3	5	5			

ANNULOSA.

Class—ANNELIDA.

Ditrupa	2	2	1	..	...
Serpula	10	6	5	..	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Serpulorbis	1	...	1	...	...
Vermicularia	1	1	...	...	...
Vermilia	1	1	1	...	...
5	15	10	8		

Class—CRUSTACEA.

Cirripedia.

Balanus	2	1	1	...	...
Pollicipes	1	...	1	...	...
Scalpellum	1	1	...	...	...
3	4	2	2		

Brachyura.

Campylostoma	1	1	...	...	...
Cyclocorystes	1	1	...	...	...
Litoricola	2	2	...	...	...
Goniochele	1	1	...	...	...
Goniocypoda	1	1	...	...	...
Mithracia	1	1	...	...	...
Necrozius	1	1	...	...	...
Palæocorystes	1	1	...	...	...
Rachiostoma	2	2	...	...	...
Ædisoma	1	1	...	...	...
Plagiolophus	1	1	...	...	...
Portunites	1	1	...	...	...
Xanthilites	1	1	...	...	...
Xanthopsis	4	4	...	...	...
14	19	19			

Macroura.

Archæocarabus	1	1	...	...	...
Dromilites	2	2	...	...	...
Hoploparia	2	2	...	...	...
Scyllarida	2	2	...	...	...
Thenops	1	1	...	...	...
Trachysoma	1	1	...	...	...
Callianassa	1	...	1	...	...
7	10	9	1		

Isopoda.

Eosphæroma	3	...	...	3	...

Entomostraca.

Bairdia	2	...	2	...	...
Branchipodites	1	...	...	1	...
Candona	2	1	...	1	...
Cythere	12	6	5	1	...
Cytherella	4	3	3	...	...
Cythereis	3	1	2	...	...

		No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Cytheridea		6	2	3	4	...
Cytherideis		3	...	2	1	...
Krithe		1	...	1	...	...
9		34	13	18	8	

MOLLUSCA.

MOLLUSCOIDA.

Class—POLYZOA.

Biflustra	1	1	...	...	...
Cellepora	1	...	1	...	...
Dittoaria	1	1	...	...	...
Eschara	1	...	1	...	...
Flustra	1	1	...	...	...
Idmonea	1	...	1	...	...
Lunulites	1	1	1	...	...
7	7	4	4		

BRACHIOPODA.

Lingula	1	1	...	...	...
Terebratula	1	...	1	...	...
Terebratulina	1	1	...	...	...
3	3	2	1		

PELECYPODA.

Monomyaria.

Anomia	2	2	1	...	...
Avicula	3	3	1	...	...
Lima	5	...	5	...	...
Ostrea	27	12	17	3	...
Pecten	13	4	9	...	...
Pinna	5	4	1	...	...
Spondylus	1	...	1	...	...
Vulsella	1	...	1	...	...
8	57	25	36	3	

Dimyaria.

Arca	17	3	13	1	...
Astarte	6	5	1	...	...
Byssoarca	1	1	...	...	...
Cardita	19	4	16	1	...
Cardilia	1	...	1	...	...
Cardium	14	5	10	...	...
Chama	8	1	7	...	...
Clavagella	1	...	1	...	...
Corbula	16	7	8	4	...
Crassatella	12	...	12	...	...
Cryptodon	2	2	...	...	...
Cultellus	1	1	1	...	...
Cucullæa	1	1	...	...	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Cypricardia	3	...	3	...	...
Cyprina	4	4	...	...	...
Cyrena	15	7	5	4	...
Cytherea	31	12	17	2	...
Diplodonta	1	...	1	...	...
Dreissena	1	...	1	...	...
Gastrochæna	3	2	1	...	...
Glycimeris	1	1	...	...	...
Isocardia	1	1	...	...	...
Leda	10	7	4	1	...
Limopsis	2	...	2	...	...
Lucina	10	1	9	2	...
Mactra	3	...	3	...	...
Modiola	26	8	16	4	...
Mya?	2	...	1	1	...
Mytilus	2	...	2	1	...
Neæra	3	1	2	...	...
Nucula	20	15	13	3	...
Panopæa	4	3	1	1	...
Pectunculus	10	5	5	...	...
Pholadomya	5	5	1	...	...
Pholas	3	2	1	...	...
Potamomya	2	...	2	...	...
Psammobia	5	3	3	...	...
Sanguinolaria	2	1	1	...	...
Saxicava	1	1	...	...	...
Solecurtus	1	1	1	...	...
Solen	4	...	4	...	...
Sphærium	1	...	...	1	...
Syndosmya	1	...	1	...	...
Tellina	26	1	26	...	...
Teredina	1	1	...	...	...
Teredo	1	1	...	...	...
Thracia	2	1	1	...	...
Trigonocælia	2	...	2	...	...
Unio	5	2	3	2	...
Verticordia	4	3	1	...	...
50	317	119	203	28	

PTEROPODA.

None.

GASTEROPODA.

Achatina	1	...	...	1	...
Actæon	5	2	5	...	...
Adeorbis	1	...	1	...	...
Ampullaria	2	1	2	...	...
Ancillaria	5	...	5	...	...
Ancylus	1	...	...	1	...
Aporrhais	1	1	...	...	...
Auricula	1	1	...	...	...
Bifrontia	5	...	5	...	...
Borsonia	4	...	4	...	...
Buccinum	4	2	2	...	...
Bulimus	4	...	4	2	...
Bulla	17	5	14	...	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Calyptræa	2	1	1	...	...
Callia	1	...	...	1	...
Cancellaria	8	3	8	...	...
Capulus	1	...	1	...	...
Cassidaria	5	3	3	...	...
Cerithium	44	7	35	6	...
Chemnitzia	2	1	1	...	...
Chrysodomus	3	1	2	1	...
Clausilia	1	...	...	1	...
Cominella	1	...	1	...	...
Conus	9	1	8	...	...
Conorbis	2	...	2	...	...
Craspedopoma	1	...	...	1	...
Crepidula	1	...	1	...	...
Cuma	1	...	1	...	...
Cyclostoma	1	...	...	1	...
Cyclotus	2	...	...	2	...
Cypræa	15	4	12	...	...
Delphinula	1	...	1	...	...
Dentalium	6	3	4	...	...
Emarginula	1	...	1	...	...
Eulima	4	1	3	...	...
Fasciolaria	3	...	3	...	...
Fisurella	1	...	1	...	...
Fusus	30	9	19	2	...
Globulus	9	3	9	...	...
Helix	9	...	9	7	...
Hipponyx	2	...	2	...	...
Hydrobia	4	2	...	1	...
Leiostoma	3	1	2	...	...
Limnæa	21	...	21	...	...
Litiopa	1	1	...	...	...
Littorina	1	...	1	...	...
Marginella	10	1	10	...	...
Melampus	1	...	1	...	...
Melania	13	1	13	3	...
Melanatrea	2	1	1	..	...
Melanopsis	9	3	7	3	...
Metula	1	1	1	...	...
Mitra	6	1	6	...	...
Murex	13	6	9	...	...
Nassa	1	...	1	...	...
Natica	20	7	14	...	...
Nematura	1	...	1	...	...
Nerita	3	...	3	...	...
Neritina	10	5	4	2	...
Niso	1	...	1	...	...
Odostomia	3	...	3	...	...
Oliva	3	...	3	...	...
Orbis	1	...	1	...	...
Ovula	2	1	1	...	...
Paludina	7	1	6	4	...
Patella	1	...	1	...	...
Patula	2	...	1	1	...
Pedipes	1	...	1	...	...
Phasianella	1	...	1	...	...
Phorus	5	1	4	...	...
Pisania	1	...	1	...	...
Planorbis	14	2	9	7	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Pitharella	1	1	...	...	...
Pleurotoma	119	56	74	...	...
Potamides	7	...	7	...	...
Pseudoliva	5	3	3	...	...
Pupa	2	...	2	...	...
Pyrula	6	6	4	...	...
Ringicula	3	1	3	...	...
Rostellaria	6	2	5	...	...
Rotella	2	...	2	...	...
Scalaria	10	4	8	...	...
Scaphander	1	...	1	...	...
Sigaretus	1	1	1	...	...
Solarium	10	4	9	...	...
Strepsidura	2	...	2	...	...
Strombus	1	...	1	...	..
Strebloceras	1	...	1	...	...
Succinea	2	...	1	1	...
Terebellum	2	...	2	...	...
Terebra	1	...	1	...	...
Triton	5	2	3	...	...
Trochus	1	...	1	...	...
Turbo	1	...	1	...	...
Turritella	15	5	13	...	...
Typhis	3	1	2	...	...
Velletia	1	...	1	...	...
Voluta	35	6	30	2	...
Volvaria	1	...	1	...	...
99	623	175	477	50	

CEPHALOPODA.

Aturia	1	1	...	...	...
Belemnosis	1	1	...	...	...
Beloptera	2	1	1	...	...
Belosepia	3	1	2	...	...
Nautilus	6	6	...	...	...
5	13	10	3		

PISCES.

PLACOIDEI.

Myliobatidæ.					
Myliobatis	19	14	8	...	..
Ætobatis	6	2	5	...	...
Selache	1	...	1	...	...
Pristidæ.					
Pristis	4	1	3	...	...
Lamnidæ.					
Carcharodon	2	2	1	...	...
Lamna	7	3	6	...	...
Odontaspis	1	1	...	...	...
Oxyrhina	1	1	...	...	...
Nictitantes.					
Galeocerdo	1	...	1	...	...
Glyphis	1	1	...	...	...
Naisia	1	...	1	...	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Notidanidæ.					
Notidanus	1	1	1	...	...
Chimæridæ.					
Psaliodus	1	1	..	...	...
Edaphodontidæ.					
Edaphodon	3	...	3	...	...
Elasmodus	2	1	2	...	...
Squalidæ.					
Otodus	3	2	2	...	...
Spinax	1	1	...	...	...
GANOIDEI.					
Sturionidæ.					
Acipenser	1	1	...	...	...
Salamandroidei.					
Lepidosteus	2	1	1	...	...
Pycnodontidæ.					
Gyrodus	1	1	...	...	...
Periodus	1	1	1	...	...
Pycnodus	1	1	...	...	...
Phyllodus	13	13	...	...	...
Pisodus	1	1	...	...	...
Gymnodontidæ.					
Teratichthys	1	1	...	...	...
CYCLOIDEI.					
Lophiidæ.					
Loxostomus	1	1	...	...	...
Blenniidæ.					
Laparus	1	...	1	..	..
Scomberidæ.					
Acestrus	1	1	...	...	...
Bothrosteus	1	1	...	..	...
Cœlocephalus	1	1	...	..	...
Cœlopoma	2	2	...	...	...
Cœlorhynchus	2	1	1	..	...
Cybium	1	1	...	...	...
Phalacrus	1	1	...	...	...
Phaeganus	1	1	...	...	...
Rhonchus	1	1	...	...	...
Scombrinus	1	1	...	...	...
Tetrapterus	1	1	..	...	...
Gadidæ.					
Ampheristus	1	1	...	...	...
Goniognathus	2	2	...	...	...
Merlinus	1	1	...	...	...
Rhinocephalus	1	1	...	...	...
Scomber-esocidæ.					
Hypsodon	2	2	...	...	...
Labrophagus	1	1	...	...	...
Platylæmus	1	...	1	...	...
Sphyrænodus	4	2	1	...	...

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene	Miocene.
Clupeidæ.					
Megalops	1	1	...	...	...
Halecopsis	1	1	...	...	...
Muræniдæ.					
Rhynchorhinus	1	...	1	...	...
Dubiæ, Pachycephalus	1	1	...	...	...
fam. Rhipidolepis	1	...	1	...	...
Glyptocephalus	1	1	...	...	...
Gadopsis	1	...	1	...	...
Characinidæ.					
Brychætus	1	...	1	...	...
Siluridæ.					
Silurus	1	...	1	...	...
	CTENOIDEI.				
Percidæ.					
Brachygnathus	1	1	...	...	...
Cœloperca	1	1	...	...	...
Eurygnathus	1	1	...	...	...
Myripristis	1	1	...	...	...
Percostoma	1	1	...	...	...
Podocephalus	1	1	...	...	...
Synophrys	1	1	...	...	...
Sciænuridæ.					
Sciænurus	2	2	...	...	...
Labridæ.					
Auchenilabrus	1	1	...	...	...
Theutyidæ.					
Calopomus	1	1	...	...	...
Pomophractus	1	1	...	...	...
Ptychocephalus	1	1	...	...	...
67	126	91	45		
	REPTILIA.				
Crocodilia.					
Alligator	1	...	1	...	...
Crocodilus	3	1	2	...	...
Gavialis	1	...	1	...	...
Lacertilia.					
Lacerta	1	...	1	...	...
Ophidia.					
Palæophis	4	2	2	...	...
Paleryx	2	...	2	...	...
Chelonia.					
Chelone	13	10	3	...	...
Emys	6	5	1	...	...
Platemys	2	2	...	...	...
Trionyx	10	1	9	...	...
10	43	21	22		

AVES.

	No. of Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Agrillornis	1	1	...	...	...
Halcyornis	1	1	...	...	...
Odontopteryx	1	1	...	...	...
Lithornis	1	1	...	...	...
Macrornis	1	...	1	...	...
Megalornis	1	1	...	...	...
Dasornis	1	1	...	...	...
7	7	6	1		

MAMMALIA.

Anoplotherium	2	...	...	...	...
Chæropotamus	1	...	1	...	...
Coryphodon	2	2	...	...	...
Dichobune	2	...	...	2	...
Dichodon	1	...	1	...	...
Didelphis	1	1	...	...	...
Hyracotherium	2	2	...	1	...
Hyopotamus	2	...	...	2	...
Lophiodon	1	...	1	...	...
Microchærus	1	...	1	...	...
Miolophus	1	1	...	...	...
Palæotherium	5	...	...	5	...
Paloplotherium	1	...	1	...	...
Pliolophus	1	1	...	...	...
Spalacodon	1	...	1	...	...
Zeuglodon	1	...	1	..	...
16	25	7	7	10	

TABLE CV.—*Distribution of Species through the Eocene Strata of Britain, and their relation to the succeeding Miocene.*

Classes.		Genera.	Species.	Lower Eocene.	Middle Eocene.	Upper Eocene.	Miocene.
Plantæ.	Filices	24	31	$\frac{3}{24}$	$\frac{17}{19}$	...	$\frac{7}{9}$
	Palmæ	6	6	$\frac{2}{6}$	$\frac{2}{3}$	$\frac{1}{1}$	$\frac{1}{1}$
	Coniferæ	16	31	$\frac{6}{16}$	$\frac{5}{6}$	$\frac{1}{1}$	$\frac{2}{4}$
	Dicotyledones	49	176	$\frac{13}{104}$	$\frac{18}{19}$	$\frac{1}{2}$	$\frac{26}{52}$
Cœlenterata.	Rhizopoda	22	42	$\frac{17}{21}$	$\frac{9}{19}$	...	...
	Alcyonaria	3	3	$\frac{3}{3}$	...	...	...
	Actinozoa	20	53	$\frac{7}{13}$	$\frac{17}{21}$	$\frac{2}{16}$	...
Echinodermata.	Echinoidea	8	10	$\frac{2}{5}$	$\frac{6}{6}$	...	...
	Asteroidea	3	7	$\frac{3}{7}$	$\frac{1}{1}$	...	...
	Crinoidea	3	5	$\frac{2}{5}$	...	...	...
	Annelida	5	15	$\frac{4}{16}$	$\frac{2}{2}$	...	...
Crustacea.	Cirripedia	3	4	$\frac{2}{2}$	$\frac{2}{2}$	...	...
	Brachyura	14	19	$\frac{19}{19}$	...	...	...
	Macroura	7	10	$\frac{6}{9}$	$\frac{1}{1}$	...	...
	Isopoda	1	3	...	...	$\frac{1}{3}$	...
	Entomostraca	9	34	$\frac{6}{13}$	$\frac{7}{13}$	$\frac{2}{8}$	...
	Polyzoa	7	7	$\frac{4}{4}$	$\frac{4}{4}$	...	...
	Brachiopoda	3	3	$\frac{2}{3}$	$\frac{1}{1}$	...	...
Pelecypoda.	Monomyaria	8	57	$\frac{8}{16}$	$\frac{8}{16}$	$\frac{1}{3}$	...
	Dimyaria	50	317	$\frac{35}{101}$	$\frac{50}{105}$	$\frac{16}{29}$	...
	Gasteropoda	99	623	$\frac{45}{172}$	$\frac{87}{176}$	$\frac{21}{42}$	...
Cephalopoda.	Belemnosis	1	1	$\frac{1}{1}$	...	...	...
	Beloptera	1	2	$\frac{1}{1}$	$\frac{1}{1}$	...	...
	Belosepia	1	3	$\frac{1}{1}$	$\frac{2}{2}$	...	...
	Aturia	1	1	$\frac{1}{1}$	...	..	...
	Nautilus	1	6	$\frac{1}{4}$	....	...	
	Pisces	67	126	$\frac{46}{51}$	$\frac{23}{25}$	...	...
	Reptilia	10	43	$\frac{6}{31}$	$\frac{9}{23}$	...	...
	Aves	7	7	$\frac{6}{6}$	$\frac{1}{1}$	...	...
	Mammalia	16	25	$\frac{4}{7}$	$\frac{7}{7}$	$\frac{4}{16}$	...
	Totals,	465	1670	$\frac{271}{705}$	$\frac{262}{355}$	$\frac{50}{120}$	$\frac{41}{69}$

CHAPTER LIV.

MIOCENE STRATA.[1]

THE Miocene rocks comprise those later Tertiary deposits which contain less than about 35 per cent. and more than 5 per cent. of existing species of Mollusca, or those deposits in which the proportion of living species is less than of extinct forms.

The Miocene rocks are divisible into a Lower Miocene (Oligocene) and an Upper Miocene series.

History.—Britain, so far as we at present know, was a land surface, forming part of the Continent during the Miocene period. Probably the seas were shallow, and one great feature in the physical geography and history of the Miocene period was the extension of shallow lakes over the northern or *Molasse* region of Switzerland, in which the deposition of the Oligocene strata had taken place. A remarkable terrestrial flora and fauna had left their records in the lacustrine deposits.

Flora.—The flora indicates a tropical climate in the earlier part of the Miocene period in Europe, and some of the most characteristic forms have their modern representatives in India and Australia. Among these are *Sequoia*, *Quercus*, *Myrica*, *Ficus*, *Sabal*, *Laurus*, *Cinnamomum*, *Banksia*, *Ilex*, *Acer*, *Mimosa*, *Acacia*, &c. &c. The researches of Professor Heer show that the latter part of the period, as determined from the character of the flora, had become more temperate, the more frequent plants being species of *Betula*, *Populus*, *Ulmus*, *Laurus*, and *Potamogeton*, &c.

Fauna.—The fauna, through the Mollusca, shows similar results or climatal conditions on the Continent of Europe; but in the British Islands we have no evidence beyond the flora. The Mammalia are represented through the Proboscideans, *Mastodon* and *Deinotherium*, a hornless *Rhinoceros*, the solidungulate *Anchitherium* allied to the *Palæotherium*, and the oldest known representative of the Edentata, the gigantic *Macrotherium*, a huge ant-eater, intermediate between the Pangolin (*Manis*) and the *Aardvark* (*Orycteropus*). The giraffe-like *Helladotherium* has been found in the Upper Miocene Tertiary of Attica, and *Machairodus*, the sabre-toothed Tiger or Lion (Felidæ), species of this genus, existed through the Miocene, up to the Post-

[1] The supposed Miocene beds of Great Britain are those of Bovey-Tracey, the leaf-beds of Mull, and the leaf-beds of Antrim. There is, however, no stratigraphical proof showing them to be Miocene, and the only evidence as to their age is that of the plant-remains which are found in them. These beds may possibly be of Eocene age. It is indeed questionable if either a Miocene fauna or flora occurs in Great Britain, unless it be in the Hempstead beds of the Isle of Wight, and here only plants are known. Professor Judd would transfer the Hempstead beds to the Middle Oligocene.

Pliocene period, being represented not only in Europe and Britain, but in South America and India.[1]

As before stated, the Miocene deposits are not known to occur in Britain. In France, however, the Lower Miocene at Touraine (Indre et Loire), in Auvergne, Cantal and Velay, is met with in isolated, widely-extended patches, seldom more than 50 feet thick, comprising certain beds (mostly of marine origin), known as "Faluns." In the valley of the Loire occur the typical European deposits of Upper Miocene age. Among the fossils are numerous corals and 300 species of Mollusca; all the genera are those of southern latitudes, indicating a warmer climate than that of Southern Europe at the present time. About 25 per cent. of the shells of the Faluns are identical with existing species. The Mammalian remains include *Rhinoceros*, *Hippopotamus*, *Chœropotamus*, and *Mastodon*, &c.

Mayence Basin.—F. Sandberger[2] has done much to elucidate the history of the Mayence Miocene deposits, which are brackish, freshwater, and marine; Pliocene, Miocene, and Oligocene strata occur in succession. The chief interest attached to this group is through the Mammalian remains, which include the *Deinotherium*, *Microtherium*, and *Hippotherium*.[3]

Vienna Basin.[4]—Von Hauer, in his "Geologie," divides the whole group into two stages:—

I. The Sarmatian or Cerithium stage, containing 3 subdivisions—
   a. The Upper Sarmatian Tegel or Muschelteg el.
   b. Cerithium sand.
   c. Hernals Tegel.
II. Mediterranean or marine stage, divided into 5 subdivisions—
   a. Leithakalk.
   b. Tegel of Baden.
   c. Marl of Gainfahren, Grinzing, Nussdorf.
   d. Sand of Pötzleinsdorf.
   e. Sandstone of Sievering.

Greenland.[5]—Heer has described a flora in North Greenland extending as far as up to 70° N. latitude, containing 137 species, 46 of which are found in the central European Miocene basins. From

[1] *Vide* Gaudry: "Les Enchainements." Professor Boyd Dawkins: "Early Man in Britain," p. 57.

[2] "Untersuchungen über das Mainzer Tertiärbecken," 1853; and "Die Conchylien des Mainzer Tertiärbeckens," 1863.

[3] The order Proboscidea comprises the three genera, *Elephas*, *Mastodon*, and *Deinotherium*, the two latter being extinct. The order came into existence in the Miocene period, in which occur all these genera. Little is known of *Deinotherium* except through its enormous skull. In the lower jaw are two very large tusk-like incisors, bent abruptly downwards; in the true elephants they are directed forwards. *Deinotherium* hitherto has only been found in the Miocene deposits. Some naturalists would place this remarkable Miocene mammal in the order Sirenia, but the limb-bones are of Proboscidean type.

[4] Consult Von Hauer's "Geologie," p. 617 (Die Geologie und ihre Anwendung auf die Kenntniss der Bodenbeschaffenheit der österr.-ungar. Monarchie).

[5] Heer: "Flora Fossilis Arctica," p. 207, Q. J. Geol. Soc., vol. xxxiv., 1878, p. 66. Nordenskiöld: Geol. Mag., vol. iii. p. 207, 1876.

Spitzbergen (78° 56′ N. lat.) nearly the same number of plants has been named by the same investigator.[1]

India.—Messrs. Medlicott and Blanford, in their "Geology of India," treat fully of such portions of these Miocene and Oligocene strata as have been satisfactorily determined in India or traced in Asia. The massive Nari group in Sind and the Gaj group may represent the European series. The Manchhar group of Sind, nearly 10,000 feet thick, is divisible into two sections—the lower may be Miocene, and the upper may represent the Pliocene. The lower portion only contains fossils of importance, and these are Mammalia. Remains of 22 species have been recognised, all occurring in the lower section.

They include the Plantigrade and climbing *Amphicyon*, three species of *Mastodon*, one of *Deinotherium*, two of *Rhinoceros*, one of *Chalicotherium*, an ally of the *Tapiridæ* or *Brontotheridæ*, and belonging to the Perissodactyle ungulates, the pig-like *Anthracotherium*. Most of the Miocene Suillines are European; *Hyopotamus* and *Hyotherium* are both Suidæ. The cervide Ruminant, *Dorcatherium*, with *Manis*, Crocodilian, Chelonian, and Ophidian remains, complete the Mammalian and Reptilian fauna.[2]

North America.—The Miocene beds of North America, in New Jersey, Maryland, Virginia, Missouri, California, and Oregon, &c., were laid down in shallow seas; great part probably in large lakes. Such deposits have been assigned to the White River group of Hayden, in the Upper Missouri region, and attain a thickness of from 1000 to 2000 feet. About 15 or 20 per cent. of the Mollusca of the American Miocenes are identical with existing species. Leedy, Cope, and Marsh have elucidated the palæontology of these ancient lakes, and have brought to light remains of horse-like genera (Equidæ) possessing three toes—*Anchitherium*, *Miohippus*, and *Mesohippus*. The Tapir-like *Lophiodon* and *Elotherium*, which also occur in Europe, are found in America on the same horizon; the latter hog-like genus was nearly as large as the *Rhinoceros*. True Rhinoceroses—*Rhinoceros*, *Hyracodon*, and *Diceratherium*[3]—occur with Elephantoid animals allied to the *Deinoceras* and Tapir, *Brontotherium* and *Titanotherium*, both of the Family Brontotheridæ; even-toed ruminant ungulates (*Oreodonts*); the stag-like *Leptomeryx*; *Poëbrotherium*, and *Protomeryx* belonging to the Camelidæ (ungulate ruminants), with numerous Carnivores

[1] The Nares Arctic Expedition brought to light a bed of coal equal in appearance to the ordinary Palæozoic varieties. This seam occurred in Discovery Bay, 81° 45′ lat., and is nearly 30 feet thick. Heer noticed 26 species of plants, 18 of which had already been found in the Arctic Miocene Zone. This vegetation grew luxuriantly within 8° 15′ of the Pole, in a region which must have been in darkness for half the year.

[2] *Vide* Medlicott and Blanford's "Geology of India," p. 472, &c.

[3] The Miocene deposits of Europe have not hitherto yielded any remains of *Hippopotamus*, but several have been detected in the Upper Miocene of the Sewalik Hills by Dr. Falconer and Sir Proby Cautley. These ancient Indian forms differ from the existing *Hippopotamus amphibius* of Africa, in the fact that they possessed six incisor teeth in each jaw, whereas the living type has only four.

(*Amphicyon*, *Machairodus*, *Hyænodon*). In its dentition, *Hyænodon* approximates to the living Marsupial genus *Thylacinus*. *Machairodus*, the sabre-toothed Lion or Tiger, inhabited Britain, and its remains are occasionally found in our bone-caves; it ranged from the Miocene to the close of the Post-Pliocene in Britain, on the Continent of Europe, in India, and in North and South America. Among some of the smaller forms of animals occur the remains of the earliest known Castoridæ, or beavers. This family commenced with the *Palæocastor* of the Miocene in North America, and *Steneofiber* of the Miocene of France. The genus *Castor* occurs in the French Miocene, and is not uncommon in the Pliocene beds of Europe.[1]

The life of the Miocene period, comprising the forms that inhabited rivers, lakes, and shallow seas, is extremely abundant and varied in character. The Lacustrine beds have yielded an enormous number of plants, and with them countless insects and numerous Reptiles, Birds, and Mammalia.

The plants of the Miocene period are truly prolific; our chief sources of information respecting the flora of the period is through the Brown Coals of Germany and Austria, the Lower and Upper Molasse of Switzerland,[2] and the Miocene strata of the Arctic regions. The *Lower Miocene plants* of Switzerland are mostly tropical, but include many North American forms, such as *Liriodendron* (Tulip-tree) and *Taxodium* (Cypress), *Chamærops* and *Sabal*, or the Fan Palms. As before mentioned, in Britain the so-called Lower Miocene strata of Bovey-Tracey have yielded to the researches of Heer a rich flora, including, amongst other plants, the gigantic Pine of America, *Sequoia* (*Washingtonia* or *Wellingtonia*). The Bovey species, "*Sequoia Couttsiæ*," is closely allied to the huge Californian pine, *Sequoia gigantea*. Greenland, Grinnel-land, and other parts of the Arctic regions, have revealed to us Miocene strata yielding a flora identical with species found in the European deposits. Spitzbergen alone has contributed to the critical descriptions of Heer nearly 100 species,[3] and this within 12° of the Pole, where now a dwarf willow and a few herbaceous plants constitute the only vegetation.[4]

Invertebrate Fauna.—The Invertebrata of the Miocene period are very numerous, but belong for the most part to existing types.

[1] The *Castor spælæus* of the European cave-deposits does not appear to be specifically different or separable from the existing Beaver (*C. fiber*). The great *Trogontherium* (*T. Cuvieri*) of the Post-Tertiary deposits of Europe, and in our Norwich Crag and Forest bed, &c., appears hardly generically separable from the genus *Castor*.

[2] "Le Monde Primitif de la Suisse." Heer, 1872.

[3] Heer: "Flora Fossilis Arctica. Die Fossile Flora der Polarländer," 4to. Zurich, 1868–1878. *Ib.*, "Die Miocene Flora und Fauna, Spitzbergens," 4to. 1870.

[4] Dr. Heer calculates that the Miocene flora of Europe as a whole, as known to us, comprises 3000 species; the greater portion of these are extinct. According to Heer, the American types of plants are most largely represented in the Miocene flora, next those of Europe and Asia and Africa, and lastly those of Australia. The Greenland flora indicates the existence of a temperate climate in that country, or a mean annual temperature at least 30° warmer than at present.

Rhizopoda and Actinozoa.—The Rhizopoda, through the Foraminifera, are extremely abundant. The chief forms are *Textularia*, *Robinula*, *Glandulina*, *Polystomella*, *Amphistegina*, &c. The Actinozoa (reef-forming genera) are much the same as existing species.

Insecta.—By far the most numerous class are the Insecta; they include nearly all the existing orders, and more than 1300 species have been determined by Dr. Heer from the Miocene of Switzerland alone.

Mollusca.—The Mollusca indicate a climate decidedly hotter than that now existing in the same latitude.

Fish, Reptilia, and Terrestrial **Mammalia** have been noticed under the geographical distribution of the Miocene rocks.

Aquatic Mammalia.—The Aquatic Sirenians and Cetaceans were represented in Miocene times by various genera of no special importance, amongst them *Halitherium*, which still survives. Amongst the Cetaceans are remains of *Delphinidæ*, and whales of the *Zeuglodont* family. The Miocene beds of North America have yielded two species of whales belonging to the genus Balæna, resembling the "Right Whale" of the Arctic seas.

Pachydermata.—The true Elephants (*Elephas*) do not appear to have existed during the Miocene period in Europe; but several species have been detected in the Upper Miocene deposits of the Sewalik Hills in India. Of the seven species of Miocene Elephants of India, two are allied to the existing Indian Elephant, one is related to the living African Elephants, and the remaining four appear to be intermediate between the true Elephants and the Mastodons.

CHAPTER LV.

PLIOCENE STRATA.

Crag.

Range and Characters.—The most recent of all the marine stratified deposits is also one of the most irregular. It occurs only in the eastern part of England over a narrow space slightly elevated above the sea, and ranging from the cliffs of Walton in Essex to beyond Aldborough in Suffolk. It is also known to some extent in Norfolk, particularly at Bramerton near Norwich, and has been found at Bridlington under similar conditions.

In this short course the Crag is found to rest on the London Clay at Walton and Bawdsey, and on Chalk at Bramerton. It exhibits also considerable variation of character. Its general aspect in numerous pits in Suffolk is a ferruginous mass of shells, dark pebbles, and bones and teeth of fishes, mixed up in a confused mass of sand, some-

times grouped into beds, and sometimes exhibiting oblique and disordered laminæ or false bedding, very much resembling the general character of a modern shelly beach. And from the manner in which it lies in the country about Ipswich and at Bramerton, there can be little doubt that it was deposited as an ancient beach of the German Ocean. But about Aldborough and Orford the Crag assumes a totally different character, becoming an organic accretionary shelly limestone, formed by the cementation of the Polyzoa and other groups, with shells and calcareous sand. This coralline deposit contains some of the most characteristic shells of the Coralline Crag.

The Crag deposits have hitherto been arranged under the three following groups:—

Upper group or Fluvio-marine Crag of the vicinity of Norwich, &c. Mammalia, littoral shells, &c.
Middle group or Red Crag of Suffolk. Mammalia, reptiles, fish, and multitudes of invertebrata, often much waterworn.
Lower group or Coralline Crag of Suffolk. Few or no mammalia, and abundance of invertebrata, not waterworn.

Late research, however, by Messrs. S. V. Wood and S. V. Wood, jun., F. W. Harmer, Professor Prestwich, the Rev. O. Fisher, Messrs. R. and A. Bell, and the officers of the Geological Survey (Messrs. H. B. Woodward, C. Reid, and Blake), have greatly added to our knowledge of the Pliocene deposits of the type areas, and the following stratigraphical divisions are now generally adopted:—

5. The Bure Valley Beds[1] = Lower Glacial of Messrs. Wood and Harmer.
4. Chillesford Beds = The Laminated series.
3. Fluvio-Marine Crag = The Newer Pliocene.
2. Red Crag.
1. Coralline Crag.

The only European area in which Pliocene strata attain any considerable dimensions as rock-masses, is the region of the Mediterranean. This development takes place along both flanks of the Apennine Chain and in Sicily, and reaches a thickness of several thousand feet, an accumulation deposited during the slow and continued depression of the sea-bed of the Mediterranean.

Climatic Changes in the Pliocene Period.—The general character of the flora and fauna shows without much doubt that a land passage must have existed between Britain and the Continent in pre-glacial times, so as to allow of the immigration of the plants and animals whose remains occur under the glacial deposits of the Norfolk coast. As far as evidence goes in pre-glacial ages, Britain stood higher relatively to the sea than at present. At this time also it is probable that no German Ocean existed, and the English Channel may also have been in the condition of dry land. Pre-glacial Britain therefore formed part of the European Continent, supporting a vegetation similar

[1] The term "Icenian" was proposed by Dr. S. P. Woodward for the Pliocene strata, their order of succession having been determined in the Eastern counties of England, the country of the Iceni.

to that which still characterises our area and the corresponding latitudes of Europe.

Climatal Relations.—The advent of a colder period succeeding the Miocene, is well shown in the Norwich and Red Crags of England; where a number of Northern, Boreal, or Arctic species of Mollusca make their appearance, both in the Crags and succeeding Post-Pliocene beds. The proportion of Northern forms increases considerably in the Pleistocene deposits. The period, therefore, assigned to the Pliocene series of Europe and America embraces the long interval between the warm temperate climate of the younger Miocene, and the gradually increasing cold of the succeeding Pleistocene period. Professor Prestwich, in his able paper upon the Crag beds of Norfolk and Suffolk,[1] adduces evidence of change of climate, derived from the abundance (or otherwise) of Mollusca restricted to the Northern and Southern Seas, having reference also to the total number of existing species in each of the three divisions of the Pliocene or Crag. Mr. Prestwich's enumeration is as follows:—

	Total Living Species.	Species Restricted to	
		Northern Seas.	Southern Seas.
Norwich Crag . .	130	19	11
Red Crag . . .	216	23	32
Coralline Crag . .	264	14	65

The percentage of Northern species in the Coralline or White Crag is 5.0; in the Red Crag 10.7; and in the Norwich Crag 14.6.

We have no means of estimating the period of time which must have intervened between the close of the Miocene and the commencement of the deposition of the Pliocene beds, and during which the land-surface composed of Miocene strata must have been greatly removed through sub-aërial denudation; but its duration must have been enormous. It is certain that in the Pliocene period, after long terrestrial exposure and great denudation, the greater part of the British Islands underwent a slow and probably local subsidence. We have no evidence of the amount of this depression, but it would not appear to have been great. The Eastern and South-Eastern counties began to subside after the Miocene period, and on the surfaces of the Chalk and London Clay shelly deposits were laid down or accumulated. These formations are now termed the "Crag," and are subdivided zoologically according to the proportion of living species of Mollusca.

These Pliocene deposits occur, as stated, chiefly in Suffolk. Sir C. Lyell divided the Crags into two groups—the *Older Pliocene* and *Newer Pliocene*. Two of the Crag divisions are referable to the older Pliocene, viz., the White and the Red Crags, while the Norwich Crag belongs to the newer Pliocene. Not a single species in any class is common to the Oligocene and the Pliocene strata in Britain, and we believe the same fact holds good throughout Europe. With the

[1] Q. Jour. Geol. Soc., vol. xxvii. p. 474.

Hempstead beds in the Isle of Wight, ceased all the Upper Miocene or so-called Oligocene species in Britain, and the 30 genera and 57 species of plants occurring in the Bovey-Tracey series, whatever be their age, *appeared not again* in any area. The 48 species, comprising the Hempstead fauna and 7 species of plants (or 55 together) are not met with again. The Pliocene specific fauna of nearly 1000 species was composed of entirely new forms, and represents in the 16 classes occurring in the Coralline Crag very nearly 800 species, in the Red Crag 600, and in the Norwich Crag 329 species.

Antwerp or Black Crag.

The Molluscan fauna of this lowest division of the Pliocene, the "Antwerp or Black Crag," is more ancient than that of the Coralline or White Crag of Britain, and possibly may represent the latter part of the Upper Miocene period, or a transitional series. In the Antwerp area, on the banks of the Scheldt, it lies below those beds, which are of the same age as our Red and Coralline Crag of Suffolk. We may possess a fragment of this lowest division sparingly spread over the Chalk of the South-East of England; the so-called "Box stones," or nodules containing Pectunculi and other Mollusca, may represent the Antwerp deposits or "Antwerp Crag."

Coralline Crag.[1]

Syn. { *White Crag, Suffolk Crag.*
Polyzoan or Bryozoan Crag.

This lowest division, or oldest of the Pliocene deposits of Britain, is of limited extent, ranging over an area about 20 miles in length and 3 or 4 in breadth, between the rivers Stour and Alde in Suffolk, and rarely attaining a thickness of more than 50 feet. Wherever the Red and Coralline Crags occur in the same district, the Red Crag lies uppermost; and in some places the Coralline Crag appears to have suffered denudation before the Red Crag was deposited upon it.

Fauna.—The total fauna of the Coralline Crag is 278 genera and 844 species. The analysis is as follows:—*Plantæ* $\frac{2}{2}$, *Spongia* $\frac{2}{2}$, *Foraminifera* $\frac{39}{197}$, *Actinozoa* $\frac{6}{6}$, *Echinodermata* $\frac{9}{17}$, *Annelida* $\frac{5}{13}$, *Cirripedia* $\frac{5}{12}$, *Crustacea* $\frac{14}{28}$, *Polyzoa* $\frac{33}{140}$, *Brachiopoda* $\frac{7}{8}$; *Pelecypoda: Monomyaria* $\frac{7}{31}$, *Dimyaria* $\frac{65}{163}$, *Gasteropoda* $\frac{83}{321}$, *Pisces* $\frac{9}{15}$, *Aves* $\frac{1}{1}$, *Mammalia* $\frac{8}{11}$.

Characteristic Species.—The characteristic species of the Coralline Crag are numerous, considering its varied fauna.

Among the FORAMINIFERA, *Biloculina*, *Lagena*, and *Quinqueloculina* are the most important.

CORALS.—*Cryptangia Woodii* and *Flabellum Woodii*.

ECHINODERMATA. — *Temnechinus excavatus*, *Echinus Woodwardii*, and *Brissus scillæ*.

POLYZOA.—*Cellepora* (9), *Eschara* (9), *Hornera* (11), *Idmonea* (6), *Lepralia* (32), *Membranipora* (14), and *Tubulipora* (8 species).

[1] A term commonly used in Suffolk to designate any shelly sand or gravel.

The above are the *chief Polyzoan* genera with the number of species in each; the class gives name to the formation.

BRACHIOPODA.—*Terebratula grandis, Terebratula caput-serpentis.*

LAMELLIBRANCHIATA.—*Hinnites Cortesyi, Avicula hirundo, Pecten opercularis, Artemis exoleta, Astarte Omalii, Cardita senilis, Cardium nodosum, Cyprina rustica, Cytherea rudis, Isocardia cor, Lucina borealis, Lutraria elliptica, Mactra solida, Mytilus modiolaris, Psammobia Ferroensis, Saxicava rugosa, Solecurtus candidus, Solen ensis, Tellina crassa, Thracia papyracea, Venus casina.*

GASTEROPODA.—*Buccinum Dalei, B. undatum, Calyptræa chinensis, Cancellaria mitræformis, Chemnitzia internodula, Cypræa Europea, Emarginula crassa, Fusus antiquus, Murex aciculatus, Nassa incrassata, Natica multipunctata, Pleurotoma* (many species), *Pyrula reticulata, Scalaria cancellata, Scaphander liguarius, Cassidaria bicatenata, Triton heptagonum, Trochus Zizyphinus, Trophon costiferum, T. gracile, Turritella incrassata,* and *Voluta Lamberti.*

PISCES.—*Platax Woodwardii, Otodus,* sp.

MAMMALIA.—Terrestrial:—*Mastodon arvernensis, Rhinoceros Schleiermacheri, Cervus dicranoceras.* Marine:—*Balæna mysticetus, Balænodon physaloides.*

The **Mollusca** of the Coralline Crag are mostly such as inhabit the seas of temperate regions. There is an absence of genera peculiar to hot climates, such as *Oliva, Conus, Fasciolaria, Cypræa* proper, *Voluta* being an exception. This type, however, is not that of the equatorial regions, and its living congener, *V. Junonia*, has been obtained from a depth of 1500 feet in the Gulf Stream off the American coast in extra-tropical latitude. The occurrence of the genus *Lingula* (now confined to equatorial regions) is significant, especially when associated with *Temnechinus* (*T. excavatus*), a genus of Echinoderms, believed to be extinct in the British area; but in 1869 the explorations of the "Porcupine" brought to light *Temnechinus* in the British area, and it has also been dredged off Florida by the United States Survey at 480 feet in depth. Hitherto it was supposed that all the known urchins, with notched or excavated interambulacral plates, were inhabitants of tropical seas, and belonged almost exclusively to the Indo-Pacific province. In the European seas they are, however, very rare. Mr. S. V. Wood believes that the Coralline Crag was deposited in a sea at no greater depth than 300 feet. The beds are well seen in the neighbourhood of Woodbridge, Aldborough, and Orford, also at Sutton, Ramsholt, Sudbourne, and Gedgrave, &c., &c.

Red Crag.

Like the Coralline Crag, the Red Crag has a limited geographical extension. It chiefly occurs in the county of Essex, where it rests directly upon the London Clay. In Suffolk it rarely exceeds 20 feet in thickness, and sometimes rests upon the Coralline Crag. It is chiefly composed of a dark-red or brown ferruginous shelly sand. Of its Mollusca, about 90 per cent. are living species. The Molluscan fauna number 128 genera and 450 species, 90 genera and 150 species of which pass to the Norwich Crag. Close analysis shows the following relations of the Red and Norwich Crags:—

Pelecypoda, $\frac{55}{177}$ species occur in the Red Crag, $\frac{34}{71}$ pass to Norwich Crag.
Gasteropoda, $\frac{71}{180}$ " " $\frac{34}{71}$ " "

The most noted locality for the organic remains of the Red Crag is Walton on the Naze, the ferruginous sands and clays there resting upon the London Clay, immediately north of the town. Almost every known species has occurred here. Nearly 200 are enumerated from this one locality by Mr. S. V. Wood, jun., in his Supplement to the Monograph on the Crag Mollusca.

Fauna and Characteristic Species.—The following are the characteristic species in the several classes:—

The FORAMINIFERA only number 9 species, whereas in the Coralline Crag no less than 72 are known.

CORALS.—*Solenastræa Prestwichia* and *Balanophyllia calyculus.*

ECHINODERMATA.—*Echinocyamus Suffolciensis, Echinus Henslovi,* and *Temnechinus turbinatus.*

POLYZOA.—Sixty species occur, only 3 of which are confined to the Red Crag, *Flustra distans, Hippothoa dentata, Lepralia infundibulata.*

BRACHIOPODA.—*Rynchonella psittacea.*

PELECYPODA.—*Pecten gracilis, P. septemradiatus, Astarte crebrilirata, A. obliquata, Cardita orbicularis, Cardium echinatum, C. interruptum, Corbulomya complanata, Donax trunculus, Lucina crassidens, Mactra procrassa, Modiola barbata, Mya arenaria, Nucula Cobboldiæ, Pandora pinna, Panopæa norvegica, Solen gladiolus, Tapes pullastra, Tellina prætenuis, Venus fasciata.*

GASTEROPODA.—*Actæon noæ, Buccinum striatam, Cylichna cylindrica, Dentalium entalis, Emarginula crassa, Fusus nodifer, F. sarsii, Murex erinaceus, Nassa propinqua, N. reticosa, Natica catena, Pleurotoma* (24 species), *Scalaria grœnlandica, S. Turtoniæ, Trochus granosus, T. tumidus, Trophon antiquum, T. elegans.*

MAMMALIA.—Numerous remains have occurred, chiefly from the base of the formation in Suffolk. The chief are—*Elephas antiquus, Halitherium Canhami, Hyæna antiqua, Rhinoceros Schleiermacheri, Mastodon arvernensis, Phocena orca, Hoplocetus crassidens, Hipparion,* sp., *Balænodon affinis, Canis lupus, Felis pardoides,* and *Tapirus priscus.*

The evidence drawn from the Mollusca indicates, upon the whole, a temperate or even cold climate, as compared with that of the preceding Coralline Crag. Northern types made their appearance at the close of the Red, and through the Norwich Crag a gradual decrease in temperature took place, finally culminating in the extreme cold of the glacial epoch.

Norwich Crag.

Syn. { *Fluvio-Marine, or*
Mammaliferous Crag.

Under the name of "Norwich Crag" are included all the beds in Norfolk or Suffolk which are exposed between the Glacial drift and Chalk. The newer Pliocene deposits are represented in Britain by the Norwich Crag, which consists of a few feet of incoherent shelly sand, loam, and gravel. Exposed on both banks of the Yare, as at Bramerton and Thorpe, they form patches rarely exceeding 20 feet in thickness, and at Beccles attain as much as 95 feet.

The ordinary succession comprises five subdivisions:—

PLATE XXXII.

PLIOCENE FOSSILS.

(*Crag.*)

1. *Purpura tetragona* (*Murex alveolatus*) (Sow.) Red Crag. Walton on the Naze, Sutton.
2. *Voluta Lamberti* (Sow.) Coralline and Red Crag. Felixstowe, Walton, Ramsholt.
3. *Turritella incrassata* (Sow.) Coralline and Red Crag. Sutton, Walton, Gedgrave, and recent.
4. *Natica*, sp. Red Crag. Walton.
5. *Aporrhais pes-pelicani* (Linn.) Coralline and Red Crag, Past Pliocene and Recent. Norfolk, Clyde, Sutton, Ramsholt, Newbourn, and Gedgrave.
6. *Buccinum undatum* (Linn.) Coralline Crag. Ramsholt. Red Crag. Sutton, Walton. Mam-Crag. Yorkshire and recent.
7. *Trivia* (*Cypræa*) *Europæa* (Mont.) Red and Coralline Crag. Sutton, recent.
8. *Astarte Basterotii* (Lajonk). Red Crag. Sutton and Felixstowe. Coralline Crag, Ramsholt and Sudburn.
9. *Trophon antiquum* (*Fusus*) (Müll.) Red Crag. Walton. Coralline Crag. Bramerton and recent.
10. *Temnechinus excavatus* (Wood). Coralline Crag. Ramsholt, Suffolk.
11. *Lingula Dumortieri* (Nyst.) Coralline Crag. Sutton. (Antwerp Crag.)
12. *Pyrula reticulata* (Lam.) Coralline Crag. Ramsholt.

PLATE XXXII.

PLIOCENE FOSSILS.

(*Crag*).

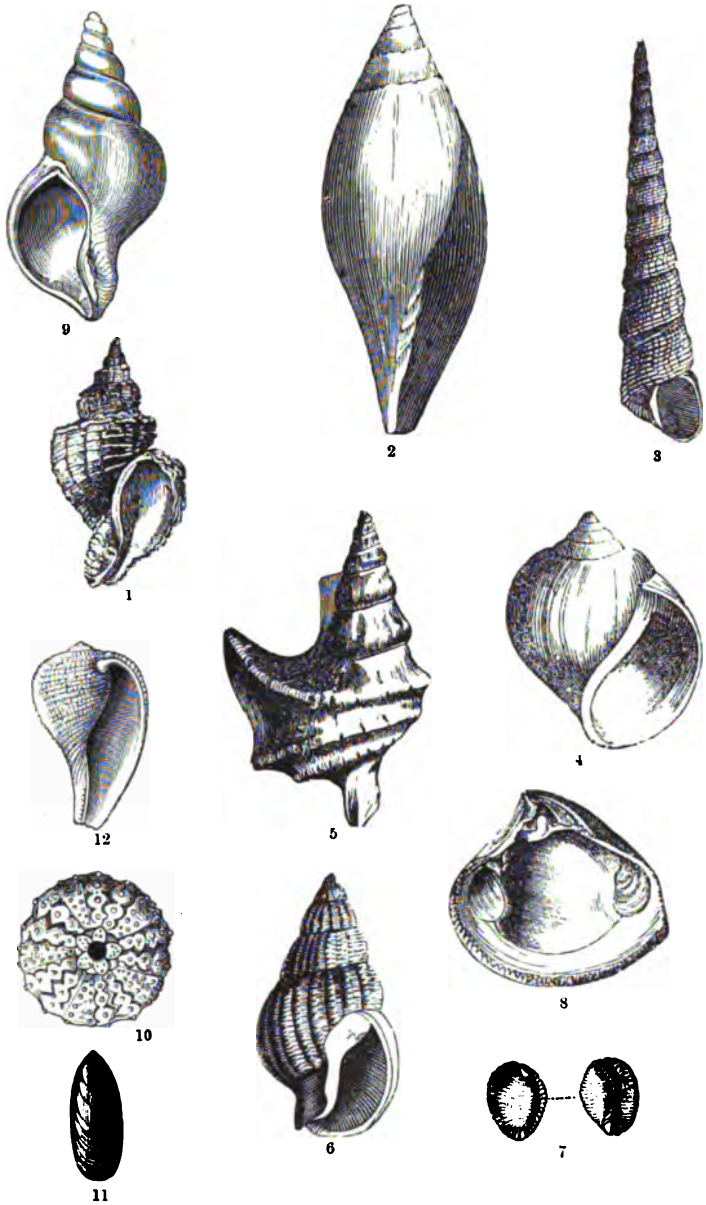

TABLE CVI.—*Numerical Distribution of the Upper Crag Fossils in the following Sixteen Chief Localities.*

	Ditchingham.	Beccles.	Aldeby.	Brundall.	Bramerton. Upper Bed.	Bramerton. Lower Bed.	Bramerton. Blake's Pit.	Kirby Bedon.	Whitlingham.	Postwick.	Thorpe.	Rockheath.	Wroxham.	Belaugh.	Coltishall.	Horstead.
Bivalves . . .	17	27	52	24	31	46	31	6	19	29	31	8	18	21	17	18
Univalves . . .	17	22	22	13	21	67	43	19	12	28	29	7	5	10	14	14
Other groups [1] . .	2	4	7	2	7	5	1	2	4	2	19	...	1	1	1	4
	36	53	81	39	59	118	75	27	35	59	79	15	24	32	32	36

Specified according to their classes, the fauna of the 16 localities is as follows:—*Spongia* $\frac{1}{1}$, *Foraminifera* $\frac{8}{8}$, *Echinodermata* $\frac{3}{3}$, *Annelida* $\frac{2}{2}$, *Crustacea* $\frac{6}{16}$, *Lamellibranchiata* $\frac{49}{85}$, *Gasteropoda* $\frac{41}{109}$, *Pisces* $\frac{3}{3}$, *Mammalia* $\frac{21}{21}$ = 225 species.

Fauna of the Upper Crag.—The whole Molluscan fauna numbers 97 genera and 231 species, viz., the Pelecypoda $\frac{41}{86}$ species, and the Gasteropoda $\frac{56}{153}$; 93 per cent. of these belong to existing species. The name, "Mammaliferous," was given to the Upper Crag from the large number of Pachydermatous and other mammalian remains (bones and teeth) occurring therein. Thus we have *Bison priscus*, *Elephas meridionalis*, *E. antiquus* and *E. primigenius*, *Hippopotamus major*, *Mastodon arvernensis*, *Trogontherium Cuvieri*, and *Ursus arvernensis*, &c. *Mastodon arvernensis* is the only species found in Britain. Of this we have only the teeth.

Characteristic Species.—Among the characteristic species are—

MOLLUSCA.—*Pecten varius*, *P. pseudo-princeps*, *Astarte borealis*, *A. crebricostata*, *Cardita borealis*, *Cardium grœnlandium*, *Cyrena* (*Corbicula*) *fluminalis*, *Donax vittatus*, *Kellia ambigua*, *Leda* (*Yoldia*) *myalis*, *Lepton nitidum*, *Lucina borealis*, *Mactra arcuata*, *Nucula Cobboldiæ*, *Panopœa Norvegica*, *Saxicava arctica*, *S. rugosa*, *Tellina fabula*, &c.

LAMELLIBRANCHIATA.—Out of the 85 known species of Norwich Crag Lamellibranchiata 9 are extinct, or no longer exist in the British seas. They are—

Astarte gracilis.	*Cardium Parkinsoni.*
Diplodonta dilatata.	*Kellia ambigua.*
Leda semisulcata.	*Mactra arcuata.*
Nucula Cobboldiæ.	*Tellina lata.*
Corbicula fluminalis.	„ *obliqua.*

[1] Echinodermata 3 species, Annelida 2, Crustacea 6, Pisces 11, Aves 2, Mammalia 21, Foraminifera 10, in the 16 localities. For all information relative to the Cretaceous and Upper Tertiary Geology of Norfolk, consult the "Geology of the Country around Norwich" (Memoirs of the Geological Survey, England and Wales), by Horace B. Woodward, F.G.S. The Pliocene and Post-Pliocene deposits are exhaustively treated of for that area. Also see Clement Reid, *loc. cit.*, pp. 8–19 and pp. 49–80.

GASTEROPODA.—Amongst this class (occurring in the Norwich Crag sea) no less than 14 species out of 132 are now extinct.

Purpura tetragona.	*Nassa reticosa.*
Columbella sulcata.	*Mangelia.*
Voluta Lamberti.	*Cassidaria bicatenata.*
Natica Bowerbanki.	*Cerithium punctatum.*
Melampus (Conovolus) pyramidalis.	,, *tricinctum.*
Nassa propinqua.	*Paludina parilis.*
Paludestrina subumbilicata.	*Trophon gracilis.*

These 14 species may be considered as characteristic of the Norwich Crag Gasteropoda.

The mixture of Arctic and Boreal species of Mollusca is a marked feature in the Norwich Crag fauna. These forms are *Rhynchonella psittacea, Scalaria grœnlandica, Astarte borealis, Panopœa norvegica, Leda myalis, L. oblongoides, Cancellaria viridula,* &c. The introduction of these northern forms may be regarded as an indication of the coming and gradual change into the Glacial Epoch, or as a "forerunner of the great invasion of arctic plants and animals" which migrated southwards into Europe from higher latitudes.

The beds grouped under the broad name of "Norwich Crag series" include representatives in time of the "Chillesford clay" or Chillesford beds.

The Chillesford Beds.

These beds, as we have seen, occur as a thin local deposit chiefly in Suffolk. Nearly two-thirds of the Mollusca in these intermittent clays still live in arctic waters.

The British species characterising the beds are—*Mya truncata, Saxicava rugosa, Astarte borealis, Tellina obliqua, T. lata, Nucula Cobboldiæ, Kellia ambigua, Cyprina Islandica, Mactra elliptica (ovalis), Panopœa norvegica,* &c. Five Lamellibranchs are now extinct. Among the Gasteropoda are—*Trophon antiquum, Purpura lapillus, Scalaria grœnlandica,* and *Natica catena.*

The shells indicate on the whole a colder climate than that of the Red Crag. In the pit at Bramerton, near Norwich, the following beds rest upon the Chalk :—

		Feet.
Chillesford beds.	Chillesford clay	1
	Chillesford sand, with shell bed . .	5
Fluvio-marine crag.	Unfossiliferous sand	12[1]
	Fluvio-marine crag	5

H. B. Woodward, *loc. cit.*

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[1] Messrs. Crowfoot and Dawson of Beccles have obtained upwards of 70 species of Mollusca, comprising the Chillesford forms. About nine-tenths are recent, and two-thirds of these are now met with in the Arctic regions. *Tellina Balthica* has not yet been found in the Chillesford or Aldeby beds.

[2] Between the Fluvio-marine Crag and Chillesford beds *here,* is a layer of unfossiliferous sand (12 feet), which Mr. S. V. Wood considers as the equivalent of

The Forest Bed Group.
Cromer Forest Bed.

The chief pre-glacial deposit of Britain occurs on the Norfolk Coast, reposing upon the Newer Pliocene or Norwich Crag beds, and consisting of an ancient land-surface known as the Cromer Forest bed. This interesting set of beds, composed of estuarine and marine deposits, occurring at the base of the glacial series, and beneath the pebbly sands and the laminated beds (= the Bure Valley beds), is exposed for many miles along the North-East coast of Norfolk, at the base of the range of glacial cliffs.[1] Its persistence along the coast is the more remarkable when we consider that there must have been a subsidence of the forest to the amount of 400 or 500 feet, and a re-elevation of the same to an equal extent (or a movement of 1000 feet), in order to allow the ancient surface of the Chalk, with its covering of soil on which the forest grew, to be first covered with several hundred feet of drift. The remains of *Elephas antiquus* are most abundant, with *Rhinoceros etruscus* and *Trogontherium Cuvieri*. The fauna comprises 80 species.

Traces of a former land-surface are shown through a band of dark carbonaceous silt and peat ("*Lower Freshwater bed*"). This is succeeded by the Forest bed, properly so called.[2] This ancient soil contains the stumps of numerous trees—many of them, however, drifted into their present site, but in an erect position; numerous mammalian remains, drift-wood, cones, and seeds occur; it is in turn overlaid by fresh-water and marine beds, the latter containing *Leda myalis* and other marine mollusca (*Trophon antiquum, Nucula Cobboldiæ, Tellina, Corbicula fluminalis*, and *Belgrandia marginata* marine, the two latter extinct). About 50 species of Mammalia, 17 species of Fishes, 2 Reptiles, and 4 Amphibians, complete the fauna of the Forest bed series.

Mammalia of the Forest Bed.—"The Mammalia of the Forest bed affords much insight into the fauna that preceded the Glacial Epoch or Ice Age in Central Europe and the adjoining seas." The Carnivora that occur are 7 genera and 8 species—*Ursus* (2), *Gulo luscus, Machairodus*, sp., *Felis*, sp., *Martes sylvatica, Trichæchus Huxleyi*, and *Phoca*, sp.

The Ungulata 7 genera and 16 species—*Equus* (2), *Rhinoceros* (2), *Hippopotamus major, Sus scrofa, Bos primigenius, Caprovis Savinii*, and *Cervus* (10 or 12 species).

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the *Scrobicularia crag* of the Chillesford section. The section is as follows at Chillesford:—

Chillesford beds.	Chillesford clay.
	Chillesford sand, with shell bed.
Red Crag.	Scrobicularia crag.
	Red crag.

The Chillesford beds are overlaid by the Bure Valley series, which forms a connecting link between the Pliocene and Glacial series.

[1] Its present relation to the lower portions of the Norwich Crag series has not been determined; its thickness, therefore, is unknown.

[2] See complete and detailed history of the Forest bed, "Geol. of Country around Cromer," by Clement Reid (Mem. Geol. Survey, 1882).

Rodentia 7 genera—*Trogontherium Cuvieri, Castor Europæus, Arvicola intermedia, A. arvalis*, var. *A. nivalis, A. gregalis*, and *Mus sylvaticus*.

Proboscidea—*Elephas antiquus, E. meridionalis, E. primigenius*.

Cetacea—*Balænoptera, Monodon monoceros, Delphinus delphis*, and *D.*, sp.

Altogether about 80 species occur in the Forest bed, exclusive of the unnamed Cervidæ. If from the 80 species are eliminated all those which are specifically uncertain or doubtful as to the horizon from which they have been obtained, there are nevertheless some 50 species left, 30 of which are still living and 19 extinct. Seventeen of the 50 occur also in the Post-Pliocene, and 14 pass down into the Pliocene deposits. Mr. E. T. Newton,[1] in his analysis (pp. 135–8) of the distribution of the Pliocene and Post-Pliocene Mammalia, gives the following results:—

	Number of Species.	Living.	Extinct.
Coralline Crag . . .	45	0	45
Norwich Crag . . .	17 (?)	5 (?)	12
Forest Bed . . .	39	17	22
Post-Pliocene deposits .	49	41	8

On examining the table of distribution prepared by Mr. Newton, on pp. 133–4 (*loc. cit.*), we find that the lower types are the most persistent, while the larger and higher ones are more liable to change or extinction. Nearly all the Fish, Amphibia, and Reptilia are living forms, and some of the Fish belong to species which have continued from the Coralline Crag. Among the Mammalia, most of the *herbivorous* forms are *extinct*, but the greater number of the species of Rodents, Carnivores, and marine animals have lived on to the present day.

Bure Valley Beds.

(*Westleton Beds*) (Prestwich).

These sands, mostly of a deep orange colour, occur near Halesworth and Henham. The pebbly shingle-like masses are described as forming true beaches of considerable thickness.

The base of the sands when resting on the Chalk occurs as shell-patches, known as the Crag (*Tellina Balthica Crag*). It is recognised at Crastwick, Rackheath, Wroxham, Belaugh, Weybourn, Runton, and Trimmingham. These deposits range from the Bure Valley past Norwich to the neighbourhood of Southwold, and expand northwards into the Weybourn sand.[2] According to Messrs. Wood and Harmer, these beds form the base of the whole Glacial series, and indicate the first setting in of the great Glacial subsidence. They are characterised by the first appearance in England of *Tellina Balthica (solidula); Tellina obliqua, Cyprina Islandica, Leda oblongoides, Cardium edule*, and *Littorina littorea*, &c., also occur.

[1] Mem. Geol. Survey, England and Wales, "The Vertebrata of the Forest Bed Series of Norfolk and Suffolk." E. T. Newton, 1882.

[2] Mr. Horace Woodward states that, in some localities near Norwich, there is no definite line of separation between the Bure Valley beds and the Chillesford beds and Fluvio-marine Crag beneath, and he classes them together as one group. "The Norwich Crag Series," *loc. cit.*, p. 291, Geol. of England and Wales.

Pliocene Life.—As regards the *life* of the Pliocene period, there are only two classes to which much attention may really be directed, viz., the Mollusca and the Mammalia.

In the class Mollusca, new species seem to have rapidly accumulated. In the *older Pliocene* deposits the number of existing species of Mollusca was only from 40 to 60 per cent.; but in the *newer Pliocene* the proportion of living forms rises to 80 or 90 per cent.

The chief Palæontological interest of the Pliocene deposits, however, as well as of the succeeding Post-Pliocene, centres round the Mammalia, and amongst the many forms may be specially noted the orders of the hoofed quadrupeds (*Ungulates*), the *Proboscideans*, the *Carnivora*, and the *Quadrumana*.

Amongst the odd-toed Ungulates, in addition to the remains of the true Tapirs (*Tapirus arvernensis*), those of several species of Rhinoceros occur (*R. etruscus* and *R. megarhinus*). *R. etruscus* survived into the early portion of the Post-Pliocene period. The latter, *R. megarhinus*, is found associated with *Elephas meridionalis* and *E. antiquus* in the Pliocene deposits of the Val d'Arno, near Florence, and lived on into the earlier portion of the Post-Pliocene period.

The horses (*Equidæ*) are represented both in Europe and America by the three-toed *Hipparions*, which survive from the Miocene. For the first time we meet with the true horse (*Equus*), in which each foot is provided with a single complete toe, encased in a single broad hoof.[1]

Amongst the even-toed Ungulates, the occurrence of swine (*Suida*), deer (*Cervidæ*), and especially *Hippopotamus* (*H. major*) in Britain and Europe, is interesting.[2] The last named is found abundantly in the Pliocene deposits of Italy and France, associated with the remains of the Elephant, Mastodon, and Rhinoceros.

The Pliocene Proboscideans are represented by the Mastodon and Elephants. The most important member of the former is *M. arvernensis*, which ranged widely over Southern Europe and England, and is found associated with the remains of *Elephas meridionalis*, *E. antiquus*, *Rhinoceros megarhinus*, and *Hippopotamus major*. The two most important Pliocene Elephants are *E. meridionalis* and *E. antiquus*. The first named occurs abundantly in the Pliocene deposits of Southern Europe and England, and survived into the Post-Pliocene period.

Amongst the Carnivora of the Pliocene period we find true Bears (*Ursus arvernensis*), Hyænas (*H. Hipparionum*), Lions (*Felis augustus* of N. America), and the strange "sabre-toothed Tiger" (*Machairodus cultridens*), probably the most highly carnivorous type of all known beasts of prey. This genus is not only European, but is represented both in South America and India.

The Quadrumana of the European Pliocene deposits are illustrated by monkeys allied to the existing *Semnopitheci* and the *Mocaques*.

[1] One of the American species of this period (*Equus excelsus*) quite equalled the modern horse in structure; but although the horse was indigenous to America at this comparatively late geological epoch, it certainly was extinct before the Spaniards discovered that continent.

[2] This species is closely allied to the living *Hippopotamus amphibius* of Africa.

Foreign Pliocene Strata.

France.—The Pliocene deposits of France are chiefly remarkable for the number of their vertebrate remains, many of which in the south indicate a higher temperature or warmer climate than that of the same region at the present day; generically, they are the same as the British Fauna, and include many of the same species. M. Gaudry contributes largely to our knowledge of the fauna of the Pliocene and Quaternary period.[1] This age is marked by the first appearance of the true Elephants, and exhibits the remnants of an older fauna through *Hyæna*, *Hipparion*, and *Machairodus*.

Faluns of Touraine.—In the Faluns of Touraine occurs a series of gravelly sands, long celebrated for abundance of shells and other organic remains. Along the line of the Loire valley at several points, as well as at Rennes, shelly and gravelly deposits occur, which are of a posterior date to the whole Parisian formation, and contain not only a variety of shells and corals distinct for the most part from those of the Parisian Tertiaries, but also a mixture of mammalian remains. Besides *Palæotherium*, *Lophiodon*, and a species of *Anthracotherium*, which would generally be referred to the era of lacustrine Tertiaries, there are bones of Mastodon, Hippopotamus, Rhinoceros, Tapir, Horse, and Deer. These deposits were wrongly compared by M. Desnoyers with those of the English Crag. The Faluns were taken by Sir C. Lyell to illustrate Miocene deposits. The affinity of the deposits of Touraine and Suffolk is, however, remarkable, and was admitted by D'Orbigny. Thus a sequence of tertiary deposits of the same general characters appears to be clearly ascertained in the south-eastern parts of England and the northern parts of France, and the beds in the two localities are the same, or nearly of the same geological period.

Belgium.—In the neighbourhood of Antwerp there occur certain Crag beds, which are the equivalents in part of the White or Coralline and Red Crag of Britain. These sandy crags overlie the Black Crag (a series of black, grey, or greenish Glauconite sands, which have been termed *Mio-pliocene*). Dumont formerly classed these strata as "*Scaldisien.*" They have recently been divided into a *lower* group, characterised by the occurrence of *Isocardia cor*, and a *higher* containing *Trophon antiquum*. M. Mourlon has named the lower sands "*anversien*" (Antwerpian).[2] They contain the British shells, *Cyprina rustica*, *Isocardia cor*, *Cardita senilis*, *Lucina borealis*, *Astarte omalii*, and *Turritella incrassata*. Mourlon's upper group (Scaldisien) possibly represents our Red Crag, the fauna being precisely the same, and containing, among many other shells, *Voluta Lamberti*, *Purpura tetragona*, *P. lapillus*, *Trophon antiquum*, *T. gracile*, *Nassa reticosa*, *Pecten maximus*, *P. gerardi*, *Ostrea* sp., &c. &c.

Switzerland—Molasse.—The primary and secondary Swiss mountains are bordered on the north by a vast thickness of conglomerates,

[1] Gaudry: "Matériaux pour l'Histoire des Temps Quaternaires." 4to. Paris, 1876. 8vo.

[2] Mourlon: "Géologie de la Belgique," tome I. Brussels, 1880.

sands, calciferous grits, and lignites with mammalian remains. These were referred by Brongniart to the interlacustrine marine beds of Paris, but the shells as yet found are few. M. Studer, of Berne, has amply described this immense and disturbed deposit.[1]

Œningen.—The limestone quarries of Œningen, near Schaffhausen, have long been celebrated for abundance of mammalia, birds, reptiles, fishes, insects, and plants, identical or very similar to existing species. The section of the whole deposit is given by Murchison,[2] who brought from this locality, in 1828, one of the most remarkable fossils which has ever been found—the entire and connected skeleton of an animal resembling a fox. The upper quarries exhibit a section of thirty feet, the beds changing downwards from brown clay into cream-coloured indurated marl, and afterward into a fissile fetid marlstone, containing flattened shells of *planorbis*, small *limnææ*, and *cyprides;* to these succeeds light-coloured, fetid, calcareous building stone, beneath which is a finely laminated bed, containing Insects, *Cypris*, shells of *Anodon*, and many plants; then follow two thin beds of fetid limestone, in the upper of which a large tortoise was found, and in the lower one the fox. Below are slaty marls and marlstones, limestone, and building-stone, with a repetition of finely laminated layers of marl, with plants and fishes; the general base is the great molasse of Switzerland. Excepting the skeleton, which is allied to the common fox of Europe, all the other quadrupeds found here are Rodentia. The insects and plants belong to European genera. Prof. Heer, of Zurich, has collected and investigated the extinct Flora and Fauna of these famous excavations.[3]

These descriptions of some of the most interesting lacustrine deposits will render it unnecessary to particularise other numerous cases in Switzerland, Germany, Hungary, Italy, and Spain, which present nearly the same phenomena, and appear to occupy the whole interval of time from the lower fresh-water formation of Paris to the glacial era, and to be represented by an equally continuous series of detached, desiccated, or dried-up lakes from that era to the present time.

Mayence Basin.—Above the Miocene clays and sands containing *Littorinella*, *Corbicula Faujasii*, and *Cerithium*, lie the Bone-sand of Eppelsheim and Lignite gravels (*Knocken-sand*). Among the numerous mammalian remains found here occur those of the *Deinotherium giganteum*, first detected in the Miocene beds of the Mayence basin associated with *Microtherium* and *Hippotherium*. *Mastodon angustidens* and *Rhinoceros incisivus* are here also associated with *Deinotherium*.

Vienna Basin.—Above the *Sarmatian* or *Cerithium* stage are the highest tertiary beds of this basin referred to the Pliocene period, and known by the name of the "*Congerian* stage," from the abundance of

[1] "Beiträge zu einer Monographie der Molasse," &c. (B. Studer.) 8vo. Berne. 1825.

[2] "On the Fossil Fox of Œningen," Trans. Geo. Soc., vol. iii. pp. 277–291.

[3] "Die Insektenfauna der Tertiärgebilde von Oeningen und von Radoboj in Croatien." 4to, Leipzig.

a bivalvic shell of that name (*Congeria*) (*Dreyssensia*), and separable into two stages or zones, the higher termed Belvedere-schotter and Belvedere-sand.

2. *Belvedere-schotter.*—A coarse conglomerate or gravel of quartz and other pebbles, yielding mammalian bones. *Belvedere-sand*—yellow micaceous sand, the lower part containing numerous terrestrial leaves.

1. *Inzersdorf Tegel.*—A deposit of clay, exceeding 300 feet in thickness, and formed under slow and continuous depression or submergence; it appears to be widely spread over the Vienna basin. The fossils are remarkable, especially the mollusca, the facies of which tends to show and confirm a condition due to an inland sea, or fresh-water accumulation, where there was no free communication with the open sea, but partaking of the nature or character of the Caspian Sea.[1] One marked and conspicuous genus of Mollusca, "*Congeria*," of which there are many species, characterises this deposit. The chief species are: *C. subglobosa*, *C. triangularis*, *C. spathula*, and other forms; *Cardium apertum*, *C. carnuntinum*, *Unio spathulata*, *Melanopsis martiniana*, *M. impressa*, *&c.* "The mammalia include *Mastodon longirostris*, *M. angustidens*, *Deinotherium giganteum*, *Acerotherium incisivum*, *Hippotherium gracile*, *Machairodus cultridens*, and *Hyæna hipparionum*." "The flora includes, among other plants, the conifers *Glyptostrobus*, *Sequoia*, and *Pinus*, with species of *Alnus* (alder), *Betula* (birch), *Laurus* (laurel), *Cinnamomum* (cinnamon), *Rhamnus* (buckthorn), *Castanea* (chestnut), *Carpinus* (hornbeam), *Liquidambar platanus* (plane), *Salix* (willow), *Populus* (poplar), with *Parrotia*, or the Persian iron wood, and the Australian proteaceous *Hakea* (Grevillea)."[2]—(GEIKIE.)

Portions of the Austro-Hungarian empire give evidence during later Tertiary time of having possessed isolated and detached areas of sea, resembling the present great Aralo-Caspian depression. The "*Congeria*" *stage* would represent an isolated gulf, gradually freshening, like the present Caspian Sea, by the inpouring or influx of fresh water.

Italy.—No region in Europe possesses such extensive Pliocene deposits as Italy, and they may be received as the typical series for Europe. The beds form a range of low hills flanking both sides of

[1] The impoverished fauna of the Caspian Sea, now separated from the ocean, is probably due, as in the Dead Sea, to slow super-saturation, becoming salter by evaporation. Any great increase of rainfall would render this inland sea transitional, or exhibit conditions of the passage from fresh-water to marine. The genus *Cardium* lives both in brackish and marine waters, and occurs in the Black and Caspian Seas so dwarfed as scarcely to be recognised as the true genus. *C. rusticum* extends from the Icy Sea to the Mediterranean, Black Sea, Caspian, and Aral. The Aral and Caspian probably made formerly, owing to the rivers that enter them, one great salt sea. The name *Aralo-Caspian* was given by Murchison and M. de Verneuil to the limestone and associated sandy beds of brackish-water origin, which have been traced over every extensive area surrounding the Caspian, Azof, and Aral Seas, and parts of the northern and western coasts of the Black Sea. The fossil shells are partly fresh-water, as *Paludina*, *Neritina*, &c., and partly marine. The living Mollusca are few, scarcely a dozen species known, and these mainly of the Cardium group, with *Mytilus edulis* and a *Dreissena* (*Mytilidæ*). The remarkable shell, "*Congeria*," mentioned above, is a sub-genus of *Dreissena*, if not truly *Dreissena*, resembling our own fresh-water form. Two or three species only are known or quoted as coming from the Aral—*Cardium Edule* and *Adacna vitrea*. The *Cardiadæ* and *Mytilidæ* are hence capable of enduring wide extremes in the saline conditions of water.

[2] Consult Von Hauer: "Die Geologie und ihre Anwendung auf die Kenntniss, &c.," 8vo, Vienna, 1875.

the Apennine chain,[1] and hence have received the name "*Subapennine series.*" They attain a thickness of about 3000 feet, being most massive (or having thicker deposition) towards the south.

No one since Brocchi has been more successful in the examination of the Subapennine strata than Sir C. Lyell, and they furnished much of the evidence which supports his classification of the tertiary system into Eocene, Miocene, and Pliocene formations according to the degree of analogy which the organic fossils of those groups bear to existing species of marine life. They are of enormous thickness (several thousand feet), and must have required vast time for their accumulation in the Mediterranean area, from which they have been uplifted to considerable elevations on each side of the secondary Apennine ridges. The mass consists of innumerable alternations of calcareous and argillaceous marl, light brown or grey; but the variation of mineral character is slight through the whole series, and not at all sufficient to furnish permanent marks of separation into lithological groups. It is altogether like the sediment quietly deposited on the bed of the Mediterranean by rivers which have left their coarser detrital matter inland. Beds of lignite are sometimes interstratified, as at Medesano, near Parma. Subordinate beds of gypsum, interstratified with shelly marls and sand, also occur in the Parmesan. The whole is covered in places, and unequally, by a coarse yellow sand and conglomerate, in which alternations of fluviatile and marine remains are traceable, and other conditions prevail which mark estuarine or littoral action.

This may be taken as the character of the *middle* Subapennine formation. The tertiary strata in the hill called the Superga, in Piedmont, have been described by M. Brongniart and other writers, and from personal examination Lyell inferred that they are the *oldest* part of the tertiary system in Italy. Fine green sand and marl, and a subjacent conglomerate (the boulders being of primary rocks), compose these strata, which dip at the high angle of 70°, under the more horizontal bluish Subapennine marls of the plains of the Tanara.

The Subapennines in Sicily are divided by Sequenza into 3 stages, and in descending order are—[2]

3. Astien—or yellow sands.
2. Plaisancien—blue clays or marls.
1. Zancléen—marly beds and light-coloured limestone.

"At several points north of Catania, on the eastern coast of Sicily, marine strata occur, associated with volcanic tuffs and lavas, which belong to the period when the first igneous eruptions of Etna were taking place. These marine strata contain numerous fossil shells,

[1] The Apennines are chiefly composed of Secondary Rocks, forming a chain which branches off from the Ligurian Alps, and passes down the middle of the Italian peninsula. Brocchi was the first Italian geologist who described this newer group in detail, naming it *Subapennine* ["Conchiologia Fossile Subapennina con asservazioni geologiche sugli Apennini e sul suolo adjacente." 2 vols., Milan, 1874.]

[2] Bull. Soc. Géol. de France, 2nd sér., vol. xxv. p. 465.

and out of 142 species all but 11 are identical with species now living." "*Since the accumulation* of these newer Pliocene strata, *the whole cone* of Etna, 11,000 feet in height, and about 90 miles in circumference at its base, has been slowly built up." It was during the accumulation of the Pliocene strata that the history of Etna began; the first stages being submarine eruptions, which were succeeded by the piling up of the present vast subaerial cone upon the upraised Pliocene sea-bed. There is probably no part of Europe where the newer Pliocene formations enter so largely into the structure of the earth's crust, or rise to such heights above the sea level as Sicily, where they reach the elevation of 3000 feet. According to Philippi,[1] 35 species out of 124 obtained in the Central Sicilian beds are extinct. The strata consist of two divisions, an upper and lower—the upper is calcareous and the lower argillaceous. The upper or calcareous member of this group in Sicily resembles the calcaire grossier of Paris; in other parts it is a rock nearly as compact as marble, its aggregate thickness amounting to 700 or 800 feet.

Palæontology of the Italian Pliocene Strata.—The Italian Pliocene deposits, although chiefly marine, also contain intercalations of fluviatile or lacustrine strata. The newer Pliocene deposits of the upper Val d'Arno attain a thickness of nearly 800 feet. The older portion consists of blue clays and subordinate beds of Lignite, and exhibits a richer Flora than the overlying newer Pliocene beds. This Flora is transitional between the luxuriant vegetation of the Miocene and that of recent or modern Europe. It, however, comprises many species common to the antecedent Meiocene period. M. Gaudin enumerates a large series of flowering plants,[1] *Pinus, Glyptostrobus, Taxodium, Sequoia, Ilex, Quercus, Platanus, Prunus, Alnus, Ulmus, Ficus, Laurus, Persea, Oreodaphne, Cinnamomum, Cassia, Juglans, Acer, Betula, Rhamnus, Smilax, Sassafras,* and *Psoralea,* &c. This assemblage indicates a warm climate, but hardly so subtropical as that of the Upper Miocene, which we have considered. The upper 200 feet of these blue clays and sands have yielded the remains of *Mastodon arvernensis, Elephas meridionalis, Hippopotamus major,* and *Rhinoceros Etruscus,* with *Ursus, Hyæna, Felis,* &c. Most of these occur in the Cromer Forest-bed. Many of the Mollusca of the Italian Pliocene beds are tropical, while the still living Mediterranean or Lusitanian genera are very abundant also.

India.—In the North-Western tract of India, including Sind and the Punjab, the Indian Survey has shown that from the Upper Cretaceous to the Pliocene beds (with some local exceptions) the entire succession of strata is conformable and continuous, containing evidence of alternations of marine and terrestrial conditions. The Manchhar group, composed of clays, sandstones, and conglomerates, 5000 feet thick, may be referable to the Pliocene Period. Similar strata are exposed in the Sub-Himalayas, which flank the main chain,

[1] "Fauna Molluscorum Viventium et in tellure tertiaria fossilium Regni utriusque Siciliæ." 4to, 1844. Also "Enumeratio Molluscorum Siciliæ." 4to, 1836. See Sir C. Lyell on the "Lavas and Mode of Origin of Mount Etna," Philosophical Transactions, 1858.

[2] Gaudin: Feuilles fossiles de la Toscane. 4to, Zurich, 1858. Gaudin et Strozzi: Contributions á la flore fossile italienne. Second Mémoire. Val d'Arno, 4to, Zurich, 1859. Consult also Saporta: Recherches sur les Végétaux Fossiles de Meximieux (4to, Lyons and Geneva, 1876), Archiv. Mus. Lyon, vol. i., 1875-6.

and may be from 12,000 to 15,000 feet thick; these are succeeded by younger tertiary deposits, termed the Siwalik group, and of fresh-water origin. The Molluscan fauna of the Siwalik Hills is partly land and fresh-water, and comprises mostly living species. The Mammalian fauna, of which no fewer than 93 species have been determined, includes 48 genera. In the following list those which are now extinct are lettered (e).[1]

QUADRUMANA .	*Macacus* 2 sp.; *Semnopithecus* 2 sp.
CARNIVORA . .	*Felis* 2; *Machairodus* (e) 1; *Pseudælurus* (e) 1; *Ictitherium* (e) 1; *Hyæna* 1; *Canis* (*Vulpes*) 1; *Amphicyon* (e) 1; *Ursus* 1; *Hyænarctos* (e) 2; *Mellivora* 1; *Meles* 1; *Lutra* 1; *Enhydriodon* (e) 1.
PROBOSCIDEA . .	*Elephas* 7; (*Euelephas* 1; *Loxodon* 1; *Stegodon* (e) 5); *Mastodon* (e) 4; (*Pentalophodon* (e) 2; *Tetralophodon* (e) 1; *Trilophodon* (e) 1).
UNGULATA PERISSODACTYLA.	*Rhinoceros* 6; *Acerotherium* (e) 1; *Listriodon* (e) 1; *Equus* 2; *Hipparion* (e) 2.
UNGULATA ARTIODACTYLA .	*Hippopotamus* (*Hexaprotodon*) (e) 1; *Hippopotamodon* (e) 1; *Tetraconodon* (e) 1; *Sus* 3; *Hippohyus* (e) 2; *Chalicotherium* (e) 1; *Merycopotamus* (e) 1; *Cervus* 3; *Dorcatherium* (e) 2; *Camelopardalis* 2; *Sivatherium* (e) 1; *Hydaspitherium* (e) 3; *Bos* 3; *Bison* 1; *Bubalus* 2: *Peribos* (e) 1; *Amphibos* (e) 1; *Hemibos* (e) 1; *Antilope* 4; *Capra* 2; *Ovis* 1; *Camelus* 1.
RODENTIA . .	*Mus* 1; *Rhizomys* 1; *Hystrix* 1.

Mr. Blanford[2] shows "that though usually classed as Miocene, the Siwalik Fauna has such relations to Pliocene and recent forms as are found *in no true* Miocene fauna."

"Among the genera 12 are unknown elsewhere; 7 are Miocene and Pliocene; of the still living genera 9 range back in Europe to upper Miocene time, 10 only to Pliocene, while 0 are only known elsewhere as living forms, or as occurring in Post-Pliocene beds.

TABLE CVII.—*Numerical Distribution of the Fauna and Flora of the Pliocene or Crag Deposits.*

Classes.	Genera.	Species.	Coralline Crag.	Red Crag.	Mam. Crag.
Plantæ	1	1	...	...	$\frac{1}{1}$
Rhizopoda	30	95	$\frac{26}{76}$	$\frac{5}{19}$	$\frac{14}{19}$
Actinozoa	10	12	$\frac{9}{9}$	$\frac{10}{10}$	$\frac{1}{1}$
Echinodermata . . .	12	30	$\frac{9}{28}$	$\frac{8}{14}$	$\frac{6}{6}$
Annelida	8	18	$\frac{7}{14}$	$\frac{6}{6}$	$\frac{2}{4}$
Cirripedia	6	15	$\frac{4}{11}$	$\frac{4}{10}$	$\frac{2}{2}$
Crustacea proper . . .	13	25	$\frac{13}{23}$	$\frac{8}{9}$	$\frac{3}{3}$
Polyzoa	32	139	$\frac{30}{134}$	$\frac{23}{61}$	$\frac{15}{18}$
Brachiopoda	7	9	$\frac{6}{8}$	$\frac{2}{2}$	$\frac{1}{1}$
Monomyaria	7	34	$\frac{7}{28}$	$\frac{6}{17}$	$\frac{3}{10}$
Dimyaria	72	224	$\frac{63}{148}$	$\frac{56}{138}$	$\frac{33}{59}$
Gasteropoda . . .	83	416	$\frac{64}{306}$	$\frac{61}{230}$	$\frac{52}{134}$
Pteropoda	1	1	$\frac{1}{1}$	...	...
Pisces	16	27	$\frac{9}{15}$	$\frac{11}{13}$	$\frac{4}{7}$
Mammalia	30	57	$\frac{0}{0}$	$\frac{12}{43}$	$\frac{16}{16}$
	328	1103	$\frac{253}{761}$	$\frac{218}{575}$	$\frac{164}{319}$

[1] See Medlicott & Blanford, "Geol. of India," p. 577; Blanford, Brit. Asso. 1880, p. 578.

[2] Brit. Assoc. Reports, 1880, p. 578.

TABLE CVIII.—*Organic Remains of the Pliocene or Crag Deposits.*

(See Plate XXXII. for a few species.)

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
PLANTÆ.				
Nullipora. .	1	...	...	1
PROTOZOA.				
Class—RHIZOPODA.				
Amphistegina .	1	1	...	...
Anomalina .	1	1	...	...
Biloculina .	7	7	...	1
Cristellaria .	1	...	...	1
Cassidulina .	1	...	...	1
Cornuspira .	2	2	...	...
Dendritina .	1	1	...	...
Dentalina .	1	1	...	...
Dimorphina .	2	2	...	...
Glandulina .	1	1	...	...
Globigerina .	1	1	...	1
Globulina . .	1	1	...	...
Guttulina . .	3	3	...	..
Lagena . .	11	10	...	2
Nonionina .	3	...	...	3
Operculina .	1	1	...	...
Planorbulina .	1	1	...	...
Polymorphina .	16	15	7	3
Polystomella .	2	1	...	1
Quinqueloculina	15	12	2	2
Robulina . .	2	1	...	1
Rosalina . .	1	1	1	1
Rotalina . .	4	3	1	...
Spirolina . .	1	1	...	...
Spiroloculina .	4	3	...	...
Textularia .	2	...	...	2
Triloculina .	3	2	...	1
Truncatulina .	2	1	...	1
Vaginulina .	3	2	1	1
Webbina . .	1	1	...	...
—	—	—	—	—
30	95	76	12	22
CŒLENTERATA.				
ACTINOZOA, &c.				
Alcyonium .	1	1	1	...
Balanophyllia .	1	..	1	...
Caryophyllia .	1	1	1	...
Cryptangia .	1	1	1	...
Flabellum .	2	1	1	...
Fungia . .	1	1	1	...
Solenastræa .	1	...	1	...
Sphænotrochus .	2	1	1	1
Trochocyathus .	1	...	1	...
Thecopsammia .	1	...	1	...
—	—	—	—	—
10	12	6	10	1
Class—ECHINODERMATA.				
Amphidetus .	1	1	...	...
Brissus . .	1	1	...	...
Cidaris . .	1	1	...	...
Echinarachinus	1	...	1	...
Echinocyamus .	4	3	4	1
Echinus . . .	9	8	3	1
Psammechinus .	2	1	1	...
Spatangus .	2	2	2	1
Temnechinus .	4	3	1	1
Toxopneustes .	1	...	1	1
ASTEROIDEA.				
Uraster . .	1	...	1	1
CRINOIDEA.				
Comatula . .	3	3	...	...
—	—	—	—	—
12	30	23	14	6
Class—ANNELIDA.				
Cyclogyra . .	1	1	...	...
Ditrupa . .	2	2	...	...
Filigrana . .	1	1	1	1
Sabellaria . .	1	...	1	1
Serpula . .	1	1	...	...
Spirorbis . .	5	4	1	...
Vermilia . .	3	3	3	...
Vermetus . .	4	2	3	...
—	—	—	—	—
8	18	14	9	2
CRUSTACEA.				
CIRRIPEDIA.				
Acasta . .	1	1	...	...
Balanus . .	10	8	7	4
Coronula . .	1	...	1	...
Pyrgoma . .	1	...	1	...

TABLE CVIII.—(*Continued.*)

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Scalpellum	1	1	...	...
Verruca	1	1	1	1
6	15	11	10	5
Brachyura.				
Cancer	1	1	1	1
Carcinus	1	1	1	1
Ebalia	1	1	...	...
Maia	1	1	...	...
Portunus	2	2	...	1
Gonoplax	1	1	...	...
Inachus	1	1	...	...
Anomura.				
Pagurus	1	1	...	...
Ostracoda.				
Cythere	9	7	4	...
Cytheridea	2	1	1	...
Cythereis	2	2	...	...
Cytherideis	2	2	2	...
Loxoconcha	1	1	...	...
13	25	22	9	3

MOLLUSCA.

Division—MOLLUSCOIDA.

Class—POLYZOA.

Alecto	4	3	3	1
Alveolaria	1	1	1	...
Alysidota	2	1	1	1
Biflustra	1	1	...	1
Cellaria	1	1	1	...
Cellepora	9	9	7	2
Crisia	1	1	...	...
Cupularia	3	3	1	...
Diastopora	1	1	1	...
Discoporella	2	2	1	...
Defrancia	2	2	...	...
Eschara	9	9	3	1
Fascicularia	2	2	1	...
Filicella	1	1	...	...
Flustra	3	3	...	...
Hemieschara	1	1	1	1
Hippothoa	4	4	2	1
Heteropora	5	5	1	1

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Hornera	11	11	5	1
Idmonea	5	5	...	...
Lepralia	33	31	14	3
Lunulites	1	1	1	..
Melicertina	1	1	1	1
Membranipora	15	14	10	4
Mesenteriopora	1	1	...	...
Patinella	1	1	1	...
Pustulipora	3	3	...	...
Retepora	4	4	3	1
Salicornaria	2	2	2	2
Scrupocellaria	1	1	...	...
Theonoa	1	1	1	...
Tubulipora	8	8	1	1
32	139	134	63	22

BRACHIOPODA.

Argiope	2	2	...	...
Discina	1	1	...	...
Lingula	1	1	...	...
Orbicula	2	2	...	...
Rhynchonella	1	...	1	1
Terebratula	1	1	1	...
Terebratulina	1	1	...	...
7	9	8	2	1

PELECYPODA.

Monomyaria.

Anomia	4	4	3	4
Avicula	2	2	...	...
Hinnites	1	1	1	1
Lima	8	8	2	...
Ostrea	4	3	2	...
Pecten	14	9	8	5
Pinna	1	1	1	...
7	34	28	17	10

Dimyaria.

Acila	1	...	1	...
Abra	2	...	2	...
Arca	3	3	2	1
Artemis	2	2	2	1
Astarte	21	13	13	10
Bornia	1	1	...	...
Cardita	8	6	5	3
Cardium	12	4	10	7
Chama	1	1	1	...
Circe	1	1	1	1

TABLE CVIII.—(*Continued.*)

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Cochleodesma	2	1	2	1
Coralliophaga	1	1	...	...
Corbicula	1	...	1	...
Corbula	5	2	3	5
Corbulora	1	...	1	...
Cryptodon	2	2	..	...
Corbulomya	1	...	1	...
Cultellus	1	1	...	...
Cyamium	1	1	...	1
Cyprina	2	2	2	1
Cyrena	1	1	1	...
Cytherea	2	2	2	1
Diplodonta	3	3	3	2
Donax	3	1	2	2
Erycinella	1	1	1	...
Gastrana	1	1	1	...
Gastrochæna	1	1	1	...
Glycimeris	2	2	1	1
Hippagus	1	1	...	...
Isocardia	2	2	1	...
Kellia	7	7	3	1
Lasea	2	2	...	...
Leda	7	2	5	5
Lepton	4	4	1	1
Limopsis	2	2	2	...
Loripes	1	1	1	...
Lucina	3	3	1	1
Lucinopsis	2	1	2	...
Lutraria	2	2	1	...
Macha	1	1	...	...
Mactra	13	8	9	4
Modiola	7	5	3	3
Modiolaria	3	2	2	1
Montacuta	6	6	1	3
Mya	2	1	2	1
Mytilus	4	1	3	2
Neæra	2	2	...	...
Nucinella	1	1	...	...
Nucula	7	5	5	3
Pandora	1	...	1	1
Panopæa	2	1	2	1
Pectunculus	1	1	1	1
Pholadidea	2	1	1	...
Pholadomya	1	1	...	...
Pholas	5	2	4	1
Pisidium	1	...	...	1
Poromya	1	1	...	...
Psammobia	4	4	..	...
Sachia	1	...	1	...
Saxicava	3	3	2	2
Scrobicularia	4	2	2	4
Solen	3	1	3	2
Sphenia	2	2	...	...
Sphærium	1	...	1	1
Tapes	5	2	4	3
Tellina	12	6	6	6
Teredo	1	1	1	...
Thetis	1	1	...	...
Thracia	5	3	2	1
Venerupis	1	1	1	...
Venus	4	3	4	3
Woodia	1	1	1	...
72	224	148	138	89
PTEROPODA.				
Cleodora	1	1	...	...
GASTEROPODA.				
Aclis	2	2	...	...
Actæon	5	4	4	3
Adeorbis	6	6	2	1
Alvania	2	2	...	...
Aporrhais	1	1	1	1
Amaura	1	...	1	...
Ancillaria	1	...	1	...
Aplysia	1	1	...	...
Buccinum	6	3	4	3
Bulla	7	5	1	1
Bullæa	4	4	...	...
Bythinia	1	...	...	1
Calyptræa	1	1	1	1
Cancellaria	15	10	10	1
Capulus	3	3	2	1
Cassis	1	...	1	...
Cassidaria	2	2	1	1
Cemoria	1	...	1	1
Cerithopsis	3	3	2	1
Chiton	5	5	...	...
Clausilia	1	1	...	...
Clavatula	13	11	10	2
Cerithium	9	8	6	3
Chemnitzia	13	10	6	2
Columbella	4	2	3	1
Conovulus	2	...	2	2
Cypræa	5	4	6	2
Cyclostrema	1	1	...	...
Cylichna	3	2	1	2
Dentalium	6	4	5	2
Defrancia	3	1	2	1
Emarginula	4	4	2	1
Erato	1	1	1	...
Eulima	9	7	5	1
Eulimella	1	...	1	...
Fissurella	2	2	1	1

TABLE CVIII.—(*Continued.*)

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Fossarus	1	1	...	...
Fusus	7	2	6	4
Helix	7	1	3	5
Hydrobia	4	1	3	2
Jeffresia	1	1	...	..
Lachesis	2	1	1	1
Lacuna	4	1	...	3
Limæa	4	...	4	3
Litiopa	1	1	...	...
Littorina	2	...	1	2
Margarita	4	2	1	1
Marginella	1	1	1	1
Melampus	1	...	1	1
Marsenia	1	1	...	...
Mitra	4	3	3	...
Murex	5	2	4	2
Nassa	18	10	13	7
Natica	15	11	15	8
Odostomia	19	16	7	2
Ovula	2	1	2	1
Paludina	5	...	2	5
Paludestrina	2	1	...	1
Patella	1	...	1	1
Planorbis	3	...	1	3
Pleurotoma	47	23	24	6
Pupa	2	...	2	2
Purpura	2	...	2	2
Pyramidella	2	2	2	...
Pyrula	1	1	1	...
Ringicula	2	2	2	2
Rissoa	17	15	5	3
Scalaria	14	10	8	5
Scaphander	2	2	2	...
Scissurella	1	1	...	...
Sigaretus	1	1	...	...
Succinea	2	...	...	...
Terebra	3	3	2	...
Trichotropis	1	1	...	...
Triton	3	3	1	...
Trochus	21	17	15	4
Trophon	21	11	15	10
Turritella	7	5	5	3
Utriculus	1	1	...	...
Valvata	2	...	...	2
Velutina	3	...	...	2
Voluta	1	1	1	1
Zua	1	...	...	1
83	416	266	239	132

Class—CEPHALOPODA.

None known.

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Class—PISCES.				
Acanthias	1	...	...	1
Anarchichus	1	...	1	...
Carcharodon	2	1	2	...
Chrysopis	1	...	1	...
Esox	1	...	1	...
Gadus	2	2	...	2
Lamna	1	...	...	1
Morrhua	4	4	...	...
Merlangus	3	3	...	...
Myliobatis	1	...	1	...
Otodus	1	1	1	...
Oxyrhina	2	1	1	...
Phyllodus	2	...	2	...
Platax	1	1	1	...
Raia	3	1	1	3
Zygobates	1	1	1	...
16	27	15	13	7

CLASS—MAMMALIA.

LAND AND FRESH-WATER.

Asinus	1	...	...	1
Canis	2	...	2	1
Castor	2	...	2	1
Cervus	4	...	3	2
Bison	1	...	...	1
Elephas	2	...	...	2
Equus	1	...	1	...
Felis	1	...	1	...
Hippopotamus	1	...	...	1
Hyæna	1	...	1	...
Lepus	2	...	...	2
Lutra	1	...	...	1
Mastodon	3	2?	2	1
Mustella	1	...	1	...
Rhinoceros	1	1	1	...
Sus	2	1	1	...
Tapirus	1	...	1	...
Tapirodon	1	...	1	...
Trogontherium	1	...	...	1
Ursus	2	...	2	1
20	31	4	19	15

MARINE.

Balænodon	6	2	6	...
Chonoziphius	2	...	2	...

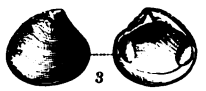
PLATE XXXII *A*.

POST-PLIOCENE FOSSILS.

1. *Pecten islandicus* (Müll.) Clyde beds, &c., reduced.
2. *Saxicava rugosa* (Penn). Clyde beds, &c.
3. *Astarte borealis* (Chem.) Glacial clays, half nat. size.
4. *Nucula Cobboldiæ* (Sow.) Glacial and Mam. Crag.
5. *Tellina proxima* (F. & H.) *lata* (Gmelin).
6. *Leda oblonga* (Sow.) (*lanceolata*). Glacial beds and Arctic seas.
7. *Trophon clathratum* (Linn.) Glacial beds.
8. *Natica clausa* (Brod.) „ „
9. *Pleurotoma rotata* (Def.) (Murex Brocc. Sub-Appenines.)
10. *Pecten pleuronectes ?*
11. Tooth of *Mastodon*, one-fourth nat. size.

PLATE XXXII *A*.

POST-PLIOCENE FOSSILS.



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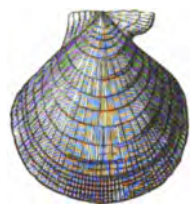

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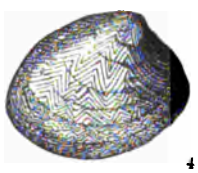

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TABLE CVIII.—(*Continued.*)

Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.	Genera.	No. of Species.	Coralline Crag.	Red Crag.	Nor. Crag.
Halitherium .	1	...	1	...	Plesiocetus .	3	2	2	1
Hoplocetus .	1	...	1	..	Trichæchus .	1	...	1	...
Phoca . .	1	...	...	1	Ziphius . .	7	...	7	...
Phocæna . .	3	1	3	1	—	—	—	—	—
Physeter . .	1	...	1	...	30	57	9	43	18

(*Including the Fresh-water Genera.*)

CHAPTER LVI.

POST-TERTIARY, POST-PLIOCENE, OR QUATERNARY PERIOD.[1]

UNDER this division or varied group of deposits are included those in which most, if not all, of the Mollusca are species still living. They occur as detached, and more or less superficial accumulations, termed by some authors "Post-Tertiary or Quaternary formation," in accordance with the nomenclature of Continental geologists. In all these deposits, whether marine or fresh-water, we meet with few or no Mollusca, except such as are now living in modern seas, lakes, or rivers. Whilst, however, the Mollusca of the Quaternary deposits are identical with existing forms, the mammalia are referable sometimes to extinct, and sometimes to living species.

In accordance with this, the Quaternary series are divided into two groups—

1. *The Post-Pliocene*, in which the Mollusca are almost invariably referable to existing species, but some of the mammalia are extinct.
2. *The Recent*, in which both the Mollusca and the Mammalia belong to existing species.

The *Recent* deposits do not properly or strictly concern the palæontologist, since they contain the remains of none but existing animals. They are pre-historic, but belong entirely to the existing Terrestrial order of things.

The Post-Pliocene[2] deposits, on the other hand, are extremely varied and very widely distributed, and contain the remains of various extinct Mammalia.

[1] In 1839, Sir Charles Lyell proposed as an abbreviation for Newer Pliocene, the term "*Pleistocene*," which was adopted by Edward Forbes in his Essay on "The Geological Relations of the Existing Fauna and Flora of the British Isles" (Mem. Geol. Surv. of Great Britain, 1846, vol. i.)

[2] The terms *Pleistocene*, *Post-Pliocene*, and *Diluvial* have been also given to the older groups of these deposits; and *Recent*, *Alluvial*, and *Human* have been assigned to the later or more modern accumulations. These subdivisions are, however, but artificial, it being often difficult to draw the line between them.

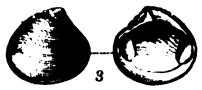
PLATE XXXII *A*.

POST-PLIOCENE FOSSILS.

1. *Pecten islandicus* (Müll.) Clyde beds, &c., reduced.
2. *Saxicava rugosa* (Penn). Clyde beds, &c.
3. *Astarte borealis* (Chem.) Glacial clays, half nat. size.
4. *Nucula Cobboldiæ* (Sow.) Glacial and Mam. Crag.
5. *Tellina proxima* (F. & H.) *lata* (Gmelin).
6. *Leda oblonga* (Sow.) (*lanceolata*). Glacial beds and Arctic seas.
7. *Trophon clathratum* (Linn.) Glacial beds.
8. *Natica clausa* (Brod.) „ „
9. *Pleurotoma rotata* (Def.) (Murex Brocc. Sub-Appenines.)
10. *Pecten pleuronectes ?*
11. Tooth of *Mastodon*, one-fourth nat. size.

PLATE XXXII *A*.

POST-PLIOCENE FOSSILS.



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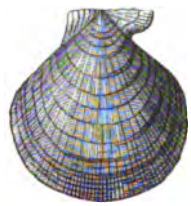

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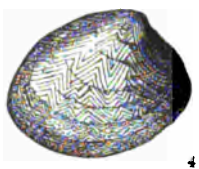

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It is most difficult to arrange the Post-Tertiary deposits in strictly chronological order, their relative antiquity being frequently obscure and doubtful. In those portions or regions of the Northern Hemisphere which have undergone glaciation, the deposits arising from that long-continued action and condition are grouped as the older division of the series under the name of Pleistocene or Post-Pliocene. Above them occur more "recent accumulations, such as river alluvia, peat-mosses, lake bottoms, cave deposits, blown sand, raised lacustrine and marine terraces, which merge insensibly into those of the present day, and are termed Recent or Pre-Historic."

At the close of the Pleistocene (Post-Pliocene) the existing distribution of land and sea appears to have been established in the Northern Hemisphere, the land presenting the same general surface-configuration and area, and the sea the same coast-line as at present, with the exception of such modifications as have since been produced by atmospheric, aqueous, and other obvious causes (meteoric). With the exception of volcanic lavas, deposits from calcareous and siliceous springs, consolidated sands, and coral reefs, we are not cognisant of new and solid strata, the generality of Post-Tertiary accumulations being, as above stated, clays, sands, silts, gravels, peat-mosses, &c.; and arranging these in chronological order, we describe them as *Post-Glacial*, *Pre-Historical*, and *Historical*.

Pleistocene or Glacial Deposits.—Under this head is included a great series of deposits which are widely spread over both Europe and America, and which were accumulated when the climate of these countries was very much colder than at present, and approached to that now known in the Arctic regions.

These accumulations are known under the general title of *Glacial deposits*, or by the more specialised names of "The Drift," "The Northern Drift," "The Till," and "The Boulder Clay," &c. In considering the numerous kinds of deposits of this age that occur in different parts of England and Wales, we are struck with their wide range and extensive distribution as compared with other and older strata; they rival, and even exceed, in thickness some if not many of the older geological horizons.

The Drift in its varied phenomena is confined to the northern half of Europe, *i.e.*, to Britain, Denmark, Scandinavia, Russia, Poland, and North Germany down to the parallel of 51° N.

In Europe the Glacial Drift materials crossed the Baltic from Scandinavia to Denmark, Germany, and Poland. Scandinavian boulders occur on the coast of Norfolk.

In Great Britain the distribution or movements were chiefly in the direction of the slopes of the mountains and their valleys—the Drift materials radiating from different centres, as in the Highlands and Southern Uplands of Scotland, the mountains of the Lake Country in Northern England, and the Snowdonian chain and other heights in North Wales. The greater part of Britain was ice-covered, together with North America, Canada, and the Eastern States down to the thirty-ninth parallel of N. latitude. Great local difference may be

observed both in the nature and succession of the different deposits of the Glacial Epoch. There appears to have been at the close of the Pliocene or Crag deposits a gradual increase of the cold, but with warm intervals, until the conditions now existing in Northern Greenland extended as far south as Wales, the South-West of Ireland, and 50° N. latitude in Central Europe. This distribution was probably the culmination of the Glacial Period, or the first or chief period of glaciation. "The existing snowfields and glaciers of the Pyrenees, Switzerland, and Norway, &c., are remains of the great ice-sheets of the Glacial Period," which extensively covered the great area depicted.

Thus from the time of the pre-glacial first bed of Norfolk, down to the latest advance of the glaciers, we have evidence of several oscillations of climate.

Professor James Geikie[1] gives the following 8 climatic changes:—

1. Pre-glacial mild period	First bed.
2. First glacial period	Cromer clay and contorted beds.
3. First interglacial mild period	Sand and rolled gravel above Cromer clay.
4. Second glacial period	Great chalky boulder clay, &c.
5. Second interglacial mild period	Beds between great chalky boulder clay and purple clay.
6. Third glacial period	Purple clay, lower boulder clay of Lancashire.
7. Third and last interglacial mild period	Hessle gravel, middle sands, &c., of Lancashire.
8. Last glacial period	Hessle clay, upper boulder clay of Lancashire.

Mr. Clement Reid has suggested that the increase of cold during the glacial period, gradually changing the character of the vegetation, doubtless rendered the country unfit for the highly specialised Ungulata, and that from this cause they gradually died out.

Pre-Glacial Land-Surfaces.—One of the best known and most conspicuous of these ancient land or terrestrial surfaces exposed is the Forest-bed of Norfolk, before noticed (p. 659). Above this bed there occurs on the Norfolk Coast a local bed of clay, containing remains of an Arctic Flora—*Salix polaris* and *Betula nana*. "These remains of a Terrestrial Flora are probably drifted, but they cannot have travelled far; they would appear to represent the Arctic Flora, which had found its way into the middle of England before the advent of the great ice-sheet. Judging from the present distribution of the same plants, we may infer that the climate had become about 20° colder than it was during the time represented by the Forest-bed—a difference as great as that between Norfolk and the North Cape at the present day."[2]—A. GEIKIE.

[1] "Great Ice Age; its Relation to the Antiquity of Man," p. 393. This important work should be consulted by every student of Geology; no short analysis of the views held by Professor Geikie could do justice to his labours. Also should be read the equally important work by Dr. Croll, "On Climate and Time in their Geological Relations." 8vo, 1875.

[2] Mem. Geol. Survey, Horizontal Section, No. 127, and Memoir Geol. Survey, "The Geology of the Country around Cromer," pp. 20–45, by Clement Reid, F.G.S.

Boulder Clay or Till.—Under this name are classed unstratified clays or loams, containing angular or sub-angular blocks of stone, many of which have been widely transported from their parent rock or original site. These frequently exhibit polished, grooved, or striated surfaces.

Stratified Drift consists of sands, gravels, and clays more or less regularly *stratified*, but often containing erratic blocks. The shells or Testacea that occur in these beds are mostly Arctic, or have an Arctic character or facies, comprising a greater or less number of forms, which are now exclusively found in the Arctic regions. When the enclosed pebbles are worn and rounded, it is due to the re-arrangement of ordinary glacial beds by the sea or rivers. These beds are known as "Drift-gravels" or Regenerated Drift. Some of these deposits are doubtless of *Post-Glacial* age.

Fauna.—The fossils of the undoubted glacial deposits are chiefly Mollusca, many of which now live in the seas of temperate regions; others are only known to occur in high latitudes, thus affording undoubted evidence of cold conditions here at the time of deposition. Amongst these Arctic species which characterise the Glacial beds, may be mentioned *Pecten islandicus*, *P. grœnlandicus*, *Scalaria grœnlandica*, *Astarte borealis*, *Leda truncata*, *L. lanceolata*, *Tellina proxima*, *T. calcarata*, *T. lata*, *Yoldia arctica*, *Saxicava rugosa*, *Trophon scalariforme*, and *Natica clausa*, &c.

Striated, Scratched, or Ice-Worn Rocks.—Beneath, or at the base of, the glacial deposits, the solid rocks, whether of limestone, fine-grained sandstone, or granite, over the whole of Northern Europe, present the smoothed, rounded outlines produced by the pressure and grinding action of the glacier or land ice. The direction of these striæ or scratches proves them to have diverged from the main masses of high ground or mountainous regions; this is finely shown in many parts of the British Islands, especially in the North and North-West and in North Wales. Each mass of elevated land—such as Snowdon, the hills of the Lake district, the Grampians, and the Southern uplands of Scotland—was once a centre of dispersion, whence the glaciers flowed downwards and outwards into the plains or into the sea. "It has been estimated that, excluding Finland, Scandinavia, and the British Islands, the ice of the glacial period must have covered no less than 1,700,000 square kilomètres of the present lowlands of Europe." "So thick must the ice-covering have been as it moved off the Scottish Highlands, that it went across the broad plains of Perthshire, filling them up to a depth of at least 2000 feet."[1] "Many Highland mountains are glaciated up to heights of 3000 feet, while lakes at their feet 600 feet deep have been well ice-worn. The present snow-fields and glaciers of the Alps, large though they are, are no more than the mere shrunken remnants of the great mantle of snow and ice which then overspread Switzerland. In the Bernese Oberland the valleys were filled to the brim with ice, which, moving northwards,

[1] Prof. A. Geikie: "Text-Book of Geology," pp. 885-901.

crossed the great plain, and actually overrode a part of the Jura Mountains."[1]

Submergence or Subsidence.—After the ice had attained its greatest development, much of North-Western Europe began to subside, and the ice-fields were carried down below the level of the sea. The most satisfactory evidence of submersion is fully supplied by beds of marine shells.

From data thus derived, we know that North Wales, as shown by Snowdon, must have been depressed at least 1300 feet below the sea-level, the surrounding area having received the marine shingle and shelly sands now seen on the summit of Moel Tryfaen 1300 feet above the bay of Caernarvon.[2] Snowdon had been severely glaciated when at its *highest elevation* or 5200 feet, and had its great moraines and deep glacier-rifts; at its greatest depression it formed an island about 1000 feet above water.[3] The Midland counties, too, sank until the Eastern part was submerged 500 feet, as shown by the Macclesfield fossils on the Pennine chain. With *less* land, and *more* water, the region became more temperate.

Second Glaciation—Re-elevation or Second Upheaval—Raised Beaches.—When the land re-emerged from its depression, the temperature over the whole of Central and Northern Europe was again severe, and there was a recurrence of cold conditions (*Last Glacial Period*). The "Raised beaches" on the British and Continental coasts testify to different stages of this uprise, and the intervening periods of rest. "To this period are ascribed certain terraces or parallel roads which run along the sides of certain valleys in the Scottish Highlands."

To account for the Arctic climate and glaciers required in the second glaciation of Wales and other areas, and for the continuous land necessary for the migration of plants and animals, this second glaciation or re-elevation was regarded by Lyell and others as *producing a Continental area*, as large as that which was characterised by the *greatest* elevation of the Alps and Snowdon, &c., and consequent greater spread or extent of land. "Every group of mountains nourished its own glaciers. On the East side of Sutherlandshire, the

[1] The wide extent of European land presented much loftier elevations than at present; the European Alps were higher; Snowdon and other hills in Britain were at least 600 feet above their present height. A cold climate accompanied these geographical conditions; the greater heights had more snow and ice; the wider lands had extreme winters; many Pliocene animals had long died out, and such only as could bear an Arctic climate survived.

[2] See Sir A. Ramsay: "Phys. Geol. and Geog. of the British Islands," and "Geol. of N. Wales," Mem. Geol. Soc., vol. iii.

[3] The chief marine shells occurring at Moel Tryfan are *Cardium echinatum*, *C. edule*, *C. rusticum*, *Astarte borealis*, *A. compressa*, *A. sulcata*, *Cyprina Islandica*, *Tellina Balthica*, *Saxicava rugosa*, *Mactra ovalis*, *Trochus magnus*, *Lucina divaricata*, *Littorina littorea*, *Turritella communis*, *Pleurotoma pyramidalis*, *P. turricula*, *Buccinum undatum*, *Natica* sp., *Nassa reticulata*, *Purpura lapillus*, *Trophon antiquum*, *T. clathratum*, *T. scalaroides*, and *Murex erinaceus*. In all, 55 species—27 Lamellibranchs and 28 Gasteropods—have been found in these Moel Tryfaen sands, &c.

moraines descend to the 50 feet raised beach. On the West side they come down still lower."

The uprise of Scandinavia and Britain took place uninterruptedly; long pauses mark the progress and extent of the platforms of erosion and deposition, or *raised beaches*, which form conspicuous features at successive heights above the present sea-level around our coast.[1]

In the later stages of the Glacial period the records are much the same all over Britain, allowance being made for the greater cold and longer lingering of the glaciers in the north than in the south, and among the hills than on the plains.

Glacial Succession in Scotland.—In Scotland the following may be assumed as the average succession of glacial phenomena in descending order:—

"*a.* Last traces of glaciers, small moraines at the foot of corries among the higher mountain-groups.
b. Marine terraces (50 feet and higher), clay beds of the arctic sea-bottom (Clyde beds), containing northern Mollusca.
c. Large moraines, coming down even to the 50-feet raised beach, showing that the glaciers of the second period descended to the sea-level in some places.
d. Erratic blocks, transplanted partly by the first ice-sheet, partly by the later glaciers, and partly by floating ice during the period of submergence.
e. Sands and gravels, Kame or Esker series, sometimes containing terrestrial organisms, sometimes marine shells.
f. Upper boulder-clays, rudely stratified clays, with sands and gravels.
g. Till or lower boulder-clay (bottom moraine of the ice-sheet), a stiff, stony unstratified clay, varying up to 100 feet or more in thickness, and containing layers of peat and terrestrial vegetation, bones of *Mammoth* and *Reindeer* (inter-glacial beds), in some places fragments of arctic and boreal Mollusca, which prove a submergence of at least 520 feet below the present level of the sea.
h. Ice-worn rock surfaces."—A. GEIKIE.

Subdivisions of the Drift.—Over a great part of England and Ireland the drift deposits are capable of the following subdivision—read upwards:—

"4. Moraines and raised beaches.
3. Upper boulder-clay, a stiff stony clay, with ice-worn stones and intercalations of sand, gravel, and silt, occasionally containing marine shells.
2. Middle sands and gravels, containing marine shells. At Macclesfield (1200 feet above the sea) the species include *Cytherea chione, Cardium rusticum, Arca lactea, Tellina balthica, Cyprina islandica, Astarte arctica*, and many other species now living in the seas around Britain. At Moel Tryfaen, near Caernarvon, 1350 feet above the sea, a similar assemblage (see note, p. 676). Near Yarmouth the Middle Glacial beds yield shells of a more southern aspect. In Ireland the middle sands and gravels have also furnished marine shells of living British species at heights of 1300 feet above the sea.

[1] If we could determine the length of time absorbed in forming these valleys and their terraces and the valley gravels, even of this period, we should know something of the length of time during which man has lived in Western Europe; for stone implements are found imbedded, often abundantly, in these gravels, and in caves along the borders of their valleys in limestone countries.

1. Lower boulder clay, a stiff clayey deposit full of ice-worn blocks, and equivalent to the till of Scotland. On the east coast of England it contains fragments of Scandinavian rocks. Along the Norfolk cliffs it presents stratified intercalations, with bands of gravel and sand, which have been greatly contorted. As in Scotland, the true lower boulder clay in the north of England and Ireland is often arranged in parallel ridges or *drums* in the prevalent line of ice movement. The so-called "Crag" of Bridlington,[1] Yorkshire, is probably a fragment of an old marine glacial shell-bearing clay, which has been torn up and imbedded in the boulder clay of the first ice-sheet."—A. GEIKIE.

Scandinavia.—The general Pleistocene phenomena in Scandinavia are much the same as in Britain, everywhere the evidence of glacial action is conspicuous and pronounced, the movement of the great ice-sheet, as shown by its walk or striæ, is outwards, or from the crest or axis of the great peninsula, down the numerous fjords into the North Atlantic and Arctic Ocean, and southwards and south-eastwards on the opposite side of the axis into the Baltic Sea and Gulf of Bothnia.

The erratic blocks attest the course or onward movement of the glaciers as well as their decrease in size or volume. Clay beds, with marine shells, show the amount of submergence which the peninsula has undergone. The varieties of *Mya truncata* and *Saxicava rugosa*, as well as *Mytilus edulis*, *Pecten islandicus*, *Buccinum grœnlandicum*, *Trophon scaliforme*, and *Natica clausa*, characterise the higher littoral shell beds, and indicate Arctic temperature or climate. The deeper water clays contain *Leda lanceolata* (*Yoldia Arctica*), *Yoldia intermedia*, *Y. pygmœa*, and *Dentalium abyssorum*. "The eastern plains of Sweden and the lower grounds of Southern Norway are marked by great accumulations of sand and gravel (ösar), like the kames of Scotland and the eskers of Ireland."

Summary of Glacial Phenomena. — Professor James Geikie, F.R.S., summarises the general results of the glacial phenomena and deposits in the following tables,[2] which embrace those of Scotland, England, Ireland, Scandinavia, Central Europe, and North America. The concise and clear descriptions are an epitome of the whole subject :—

[1] Forty-six genera and 75 species occur at Bridlington, $\frac{24}{38}$ Gasteropoda and $\frac{33}{37}$ Pelecypoda. Six species of the latter group are extinct, viz., *Astarte mutabilis*, *A. semisulcata*, *Cardita borealis*, *C. scalaris*, *Tellina obliqua*, and *Nucula Cobboldiæ;* and 2 Gasteropoda, *Fusus sabini* and *Natica Bowerbankii*. The following are a few of the characteristic species :—*Astarte borealis*, *Cardium islandicum*, *Cyprina islandica*, *Mya truncata* var. *uddavallensis*, *Panopea norvegica*, *Venus fluctuosa*, and *Corbula gibba*, *Columbella Holbollii*, *Natica grœnlandica*, *Scalaria grœnlandica*, *Trichotropis borealis*, *Trophon scalariforme*, *Fusus Spitzbergensis*, and *Pleurotoma turricula*.

[2] "The Great Ice Age and its Relation to the Antiquity of Man," pp. 488–491. This important work embraces all known on this intricate division of the later history of the globe.

TABLE CIX. (*a.*)—*Scottish Glacial Deposits.*

1. Lower accumulations of till, with subjacent and intercalated inter-glacial fresh-water and marine beds.	Intense glacial conditions, with intervening periods marked by milder conditions.
2. Fresh-water and marine deposits of last inter-glacial period.	Land surface, with trees, &c., and mammalia; temperate climate succeeded by submergence and colder conditions, Arctic and Northern shells.
3. Upper till (including most of the shelly till of maritime regions and the greater proportion of the till of inland districts).	Re-elevation of the land; intense glacial conditions, but not so excessive as before.
4. Moraine-débris and perched blocks, lake terraces, ancient flood-gravels, &c., kames, &c.	Ice sheet or confluent glaciers, retreating glacial lakes; great floods, large local glaciers.
5. Brick clays, with Arctic and boreal shells; erratics.	Further retreat of the ice; land not so extensive as now; floating ice.
6. Valley moraines and glacial gravels.	Final retreat of the glaciers.

TABLE CX. (*b.*)—*English Glacial Deposits.*

1. *a.* Cromer till and contorted drift. *b.* Gravel, sand, and clay (inter-glacial). *c.* Great chalky boulder clay of the Eastern Counties, &c., northern drift of Midland and Southern Counties; unfossiliferous bottom boulder clay of Cheshire, Somerset, &c. *d.* Gravel, sand, &c., Bridlington, &c. shell bed (inter-glacial). *e.* Purple boulder clay of Yorkshire, lower shelly boulder clay of Lancashire, Cheshire, &c.	Period of great oscillations of climate, intense glacial conditions (with confluent glaciers covering the low grounds), interrupted by milder intervals, during which the glaciers retired. Cold of the earliest recognisable glacial period (Cromer beds) not so intense as during the deposition of the great chalky boulder clay, when the climax of glacial severity was reached. Purple boulder clay, &c., indicates less severity of climate than during accumulation of the chalky boulder clay.
2. Hessle sand and gravel, with mammalian remains; *Cyrena fluminalis* and marine littoral shells, middle sand, &c., of Lancashire and Cheshire.	Last inter-glacial period; climate temperate. Yorkshire inhabited by the mammoth, horse, ox, deer; the land became submerged eventually (in Wales) to a depth of 1300 feet.
3. Hessle boulder clay, younger boulder clay of Durham, Northumberland, &c., upper shelly boulder clay of Lancashire and Cheshire.	Re-elevation of the land, return of intense glacial conditions; climate, however, not so severe as during the deposition of the chalky boulder clay, &c.
4. Moraine-débris and perched blocks on mountain slopes, &c. at high levels in Wales and the Lake Country, flood-gravels, &c.; hummocks of gravel and sand = kames.	Confluent glaciers retreating; great floods scouring the drifts of the low grounds, large local glaciers.
5. Nar Valley beds.	Climate somewhat colder than at present. Partial submergence.
6. Valley moraines.	Final retreat of the glaciers.

TABLE CXI. (*c.*)—*Irish Glacial Deposits.*

1. Till, lower boulder clay (probably the equivalent of the lower shelly boulder clay of Lancashire).	Intense glacial conditions (early inter-glacial beds not certainly known to occur).
2. Middle sand and gravel.	Last inter-glacial period; climate temperate, land submerged for upwards of 1200 feet.
3. Upper boulder clay.	Re-elevation of the land, return of glacial conditions, but climate not so cold probably as during the deposition of boulder clay.
4 and 5. Moraine-débris and perched blocks at high levels, Eskers, &c. &c.	Retreat of confluent glaciers, great floods, large local glaciers.
5. Valley moraines.	Final retreat of the glaciers.

TABLE CXII. (*d.*)—*Glacial Deposits of Central Europe.*

1. Grund-Moränen or till, perched blocks at high levels, as on the Jura, Mont Salève, &c., in Switzerland, or Ullrichsberg in Carinthia.	Intense glacial conditions; Alpine glaciers invade the low grounds of France, Baden, Würtemberg, Bavaria and Upper Austria, and the valley of the Po.
2. Lignite beds, gravel, &c., of Dürnten, &c., in Switzerland, ancient river-gravels at Klagenfurt in Carinthia, lignite and gravel, &c., of Leffe, &c., in Italy. Perhaps some portion of the so-called Pliocene sands of Piedmont, &c.	Last inter-glacial period, climate temperate, and somewhat like that of Switzerland now; elephant, rhinoceros, and great bovine and cervine animals inhabit Central Europe; *man lives* in Switzerland. Climate changes from temperate to cold-temperate and glacial.
3. Moraines overlying the older glacial and inter-glacial deposits.	Return of glacial conditions, new advance of glaciers, climate not so intense as during formation of older Grund-Moränen.
4. Diluvial gravels and sand and loess in part.	Melting of the glaciers. Great floods.
5 and 6. Newer moraines, river gravels and loess in part.	Periodic retreat of the glaciers.

TABLE CXIII. (*e.*)—*Scandinavian Glacial Deposits.*

1. Till.	Intense glacial conditions.
2. Inter-glacial Fresh-water beds.	Amelioration of climate. (There would appear to have been more than one inter-glacial period during the glacial epoch in Sweden.)
3. Till.	Return of intense glacial conditions, but glaciation not so severe.
4. Moraine-débris, perched blocks, *dsar*, &c.	Confluent glaciers retreating, great floods, local glaciers.
5. Clays, &c., with Arctic shells.	Climate still cold, land submerged for 600 feet or so.
6. Moraines.	Retreat of the glaciers.

TABLE CXIV. (*f.*)—*North American Glacial Deposits.*

1. "Till or 'unmodified drift' or '*hardpan*,' shelly boulder clay of Canada, great moraines of Rocky Mountains."	Intense glacial conditions; ice sheet covering all the North-Eastern portion of the continent, and becoming confluent in part with local glaciers of the Rocky Mountains. Great glacial lakes formed during the subsequent melting of ice-sheet.
2. "Forest-bed of North-West, &c., mammalian remains of so-called 'driftless area.'"	"Last inter-glacial period, climate mild or temperate, abundant vegetation and mammalian fauna."
3. "Upper till or '*hardpan*' covering the 'Forest-bed,' coarse gravel and sand with erratics in part."	"Return of intense glacial conditions; ice sheet not quite so extensive as before."
4. "Moraine-débris and perched blocks, lake terraces, Kames and coarse gravel and sand with erratics; flood-gravels, &c.; loess."	"Ice-sheet retreating; glacial lakes; great floods; large local glaciers in Rocky Mountains, &c."
5. "Leda clays with Arctic shells; erratics."	"Further retreat of ice; land not so extensive as now; floating ice."
6. "Valley moraines and glacial gravels."	"Final disappearance of many local glaciers."

("Great Ice Age," p. 490.)

The "foregoing tables show that *inter-glacial deposits* occur in Scotland, England, Ireland, Scandinavia, Central Europe, and North America; that they should not be equally well developed in the glacial deposits of each country" could hardly be expected. "In every country where the glacial deposits have been studied, we have clear proof of a mild inter-glacial period having supervened. The last inter-glacial period has left its mark alike in the British Islands, in Scandinavia, in Northern and Central Europe, and in North America."

"In Switzerland the climate of the period was mild and genial, the *Elephant* and *Rhinoceros* being at that time denizens of the country. In North America, during the same period, a wide-spread forest covered the North-West States and doubtless other regions, and the *Mastodon* and *Elephant* roamed over the land."

In the British deposits, after the disappearance of the great ice-sheet, underneath which the older accumulations of boulder clay were formed, a land surface appeared in the rivers and lakes. In the fluviatile and lacustrine deposits of this period in Scotland, we find the remains of the *mammoth*, and of *cervine and bovine animals*, &c. In Yorkshire, beds of the same age have also yielded mammalian bones, together with the Fresh-water shell, *Cyrena fluminalis*, which also occurs commonly in the so-called "post-glacial" beds of the Thames, associated with *Elephas primigenius* and *Rhinoceros Leptorhinus*. In Scotland and the North-West of England, there is evidence to show that this land surface was eventually submerged in a sea, whose waters were colder than those that now lave our shores."[1]

[1] Prof. James Geikie, *op. cit.*, p. 491.

Ossiferous Caves.

To the pre-glacial period belongs the greater number of ossiferous caves and fissures, containing elephant, hippopotamus, hyæna, and other extinct species of animals. Those who desire to follow the detailed history of caves and osseous breccia must be referred to the luminous pages of Buckland (*Reliquiæ Diluvianæ*),[1] and the great work of Cuvier (*Ossemens Fossiles*). We can only here present a simple analysis of the leading *results* bearing on the subject.

Caverns and fissures containing bones, however preserved, and of whatever kinds, present many important characters in common.

In some cases the existence of the cavern may be connected with dislocations of the strata, as at Greenhow Hill, in Yorkshire, yet this is rather the rare exception than the general rule. The Carboniferous limestone is full of caverns, yet not more so where numerous slips and veins divide it than in other places.

Most caverns, whatever be the character of their floor, assume at intervals along their length the appearance of a great fissure in the rocks. This circumstance is observed in the caves of Somersetshire, Derbyshire, and Yorkshire, and is recognised even in that least favourable example, Kirkdale Cave, which in its nearly level course keeps its floor nearly on one particular bed of the rock, but occasionally opens upwards into narrow irregular expansions or fissures. The fissures filled with breccia may, in fact, be often regarded as exposed caves, and resemble them in all essential circumstances.

Ossiferous Caverns, how Situated.—In the first place, they are generally, if not always, situated in stratified limestone. This circumstance has, however, apparently no relation whatever to the accident of the caves containing bones, but is merely a general fact characteristic of limestone; for in this kind of rock nearly all the caverns, grottoes, and remarkable natural fissures in the world are situated.

How Formed.—Those accustomed to underground works know it as a familiar fact, that the water which is absorbed by dry limestone land takes particular channels through the rocks, down the joints, and also along certain fissures. Every limestone hill in the Carboniferous district of the north of England shows in its *swallows* and *moor pits* the erosive power of the atmospheric or meteoric water. We, therefore, from all these considerations, believe that the enlargement or excavation of these caverns is principally owing to the subterranean passage of water charged with carbonic acid—the direction of this water, and its power of erosion, being favoured by fissures, joints, and other causes.

The most remarkable ossiferous caverns in England are Kirkdale Cave, near Kirkby Moorside, in Yorkshire; the Dream Cavern, near Wirksworth, in Derbyshire; Banwell Cave, in the Mendip Hills,

[1] See Buckland, "Reliquiæ Diluvianæ," and Cuvier, "Ossemens Fossiles," for detailed history of Caves, &c.; also "Cave-Hunting" and "Early Man in Britain," by W. Boyd Dawkins, M.A., F.R.S.

Kent's Hole, near Torquay; Oreston, near Plymouth; Cefn, near Denbigh, and Paviland, near Swansea; in Germany, the slopes of the Harz Mountains give us the caves of Baumann, of Biel, and of Schwarzfeld. Between the Harz and Franconia is the Bear Cavern of Glucksbrunn; the Jura formation near Baireuth is celebrated for the rich associated caverns of Gailenreuth, Schœnestein, Brunnenstein, Holeberg, Wieserloch, Geissloch, Wunderhohle, Rabenstein, Kuhloch, Zahnloch, Schneiderloch, Rewig, &c. In Westphalia the same Jurassic formation contains the caves of Kluterhohle and Sundwich. The caves of Adelsberg in Carniola, and the Dragons' Caves in Hungary, have also yielded bones. In France, two caverns, rich with bones, have been described by M. Thirria, near Vesoul, and several others near Montpellier and Narbonne by Marcel de Serres, Tournal, Christol, &c., and one near Miremont by M. de la Noue.

How Filled with Bones.—In some of these caves hyænas lived, and dragged into them for food other animals existing in the vicinity; bears died in others; and some were filled by the accidental falling in of browsing quadrupeds. The following are characteristic facts attending these cases.

Kirkdale Cave is one of the most remarkable instances of ossiferous accumulations known in England, both from the number of species and abundance of the bones found therein, their state of conservation, and other attendant circumstances. The entrance of this cave is on the side of a narrow valley 30 feet above the stream, in a nearly level and perfectly undisturbed bed of Coralline Oolite. It had a sort of vestibule, much larger than the interior windings of the cave, and in this lay a considerable proportion of the large bones of the elephant, rhinoceros, &c. Beyond this was a *step* in the floor, of the thickness of one bed of limestone, leading to the interior recesses, which follow an irregular line, occasionally rising to the height of 14 feet, but generally under 4 feet, and about the same breadth, but liable to contractions in both their measures. The floor was generally overspread, and its inequalities filled up by a calcareo-argillaceous substance, such as might be supposed derivable from the joints and partings of the limestone. Stalagmite in considerable quantity had dripped from the roof, incrusted the sides, and covered like a sheet the layer of mud rising upon its surface into mammillary tubercles.

In the mud, and protruding occasionally through its stalagmitic covering, lay the bones of six or seven *carnivora*, hyæna, tiger, or lion, bear, wolf, fox, and weasel; three *pachydermata*, viz., elephant, rhinoceros, hippopotamus, horse; four *ruminantia*, ox, and three kinds of deer; *rodentia*, hare, rabbit, water-rat, mouse; besides birds—raven, pigeon, lark, and duck.

The bones were scattered over this long area, "as over a dog-kennel," almost universally broken to pieces, not as if by common fracture, but by violent biting and gnawing; marks of teeth are discernible on many, exactly like those left by living hyænas on similar bones submitted to their jaws. Hyænas' teeth in great numbers, of all ages, milk teeth, shed teeth, and worn to stumps in the jaws of the

animal, abounded in the cave, besides a considerable quantity of osseous fæcal matter ("*album græcum*"), like that of the modern hyæna. From these data, most of which may be verified on the numerous specimens extracted from the cave, Dr. Buckland inferred that hyænas were for a long period the undisputed tenants of this den, lived in it for many generations, dragged into it for food, piecemeal, the bodies of animals then living in the neighbourhood, and were finally dispossessed of their hold by the slow deposition of muddy and earthy sediment. The ordinary action of water slowly passing through the calcareous rock then covered the whole with stalagmite, and closed up the bones from destructive meteoric agency. This accounts for the conservation of their gelatine. Few conclusions of this precise nature appear better supported by the facts of the case, and when we reflect on the remarkable analogy, in almost all points concerning the state and conservation of the bones, of the cavern at Torquay called Kent's Hole, and contrast these particulars of the *hyæna dens* with those of the *ox caves* in the Mendip Hills, we believe that Dr. Buckland's theory is a true interpretation of the facts.

Cave of Kuhloch.—The caves of Franconia appear to have been tenanted by bears which died in the retired parts, and were there mixed more or less with sediment and pebbles brought in by water, and the whole covered over by a stalagmitic crust formed in the usual way. The cavern of Gailenreuth is perhaps the most magnificent example of this kind; but that at Kuhloch presents some peculiarities of a very interesting nature. "It is literally true that in this single cavern (the size and proportions of which are nearly equal to the interior of a large church) there are hundreds of cart-loads of black animal dust entirely covering the whole floor, to a depth which must average at least six feet, and which, if we multiply this depth by the length and breadth of the cavern, will be found to exceed 5000 cubic feet. The whole of this mass has been again and again dug over in search of teeth and bones, which it still contains abundantly, though in broken fragments. The state of these is very different from that of the bones we find in any other caverns, being of a black or dark umber colour throughout, and many of them readily crumbling under the finger into a soft dark powder resembling mummy powder, and being of the same nature with the black earth in which they are embedded. The cave is so dry that the black earth lies in the state of loose powder, and rises in dust under the feet. It also retains so large a proportion of its original animal matter that it is occasionally used by the peasants as an enriching manure for the adjacent meadows." This cave is entered by a lofty arch, above the river Erbach, expands within both in height and breadth, and terminates in two chambers closed at the end. No fissures enter this cave; and it has no other exit than the entrance above named, except a very small passage to the same valley. There is no appearance of either stalagmite or stalactite having ever existed in this cavern.

Mendip Caves.—Dr. Buckland's views concerning the ancient occupation of hyænas and bears of the caves of Kirkdale and Franconia

derive much elucidation from the discoveries of other caverns in which the animal remains appear to have been accumulated in a different manner, especially those of Hutton in the Mendip Hills, and of Oreston near Plymouth; the former disclosed by ochre-works, the latter by quarrying for limestone. The ochre of Mendip Hills appears, in some cases, to be derived from the decomposed strata of the vicinity, and deposited in caves and fissures of the limestone by water continually passing downwards by filtration. In pursuing one of these mines of ochre near the village of Hutton, bones of many animals were discovered. The elevation of the ochre pit was 300 to 400 feet above the sea. The bones found in Hutton Hole belong to the elephant, rhinoceros, ox, horse, deer, hyæna, bear, &c.

Oreston Caves.—Three deposits of bones at Oreston, near Plymouth, were detected during the removal of the entire mass of a hill of Devonian limestone for the construction of the Breakwater. The first deposit lay in a cavern 15 feet wide, 12 high, and 45 long, and about 4 feet above high-water mark. This cavern was filled with solid clay, in which teeth and bones of rhinoceros were embedded. The second discovery was of a smaller cavern, distant 120 yards from the former, 1 foot high, 18 wide, and 20 long, and 8 feet above high-water mark. But the greatest extent of subterranean cavities was exposed by the intersection of apertures in the middle of the limestone, containing an immense deposit of bones and teeth embedded in clay. There seems, therefore, no good reason to doubt that partly in the manner described by Dr. Buckland and partly by the accidental falling of quadrupeds into open fissures of the limestone, most of the caves in Somersetshire, Derbyshire, &c., have been stored with their animal remains.[1]

[1] For every particular relative to the history of caves and Pleistocene deposits and the early inhabitants of Europe, consult "Cave Hunting; or, Researches on the Evidence of Caves Respecting the Early Inhabitants of Europe," by W. Boyd Dawkins, M.A., F.R.S., &c. Also "The Antiquity of Man," by Sir C. Lyell. For the results of much learned research, see further Dawkins's "Early Man in Britain, and his place in the Tertiary Period;" and by the same author, the monograph of the Pleistocene Mammalia in the Palæontographical Soc. vols. for 1864, 1867, and 1868. Consult also Prof. Prestwich's Report on the Exploration of Brixham Cave, with descriptions of the animal remains by Prof. G. Busk, F.R.S., and of the flint implements by Mr. John Evans, F.R.S., Trans. Royal Soc., vol. for 1873.

TABLE CXV.—*Numerical Distribution of the Post-Pliocene (Pleistocene or Quaternary) Deposits.*

Classes.	Genera.	Species.	Land and Fresh-water.	Marine.	Living British.[1]
Plantæ	71	103	$\frac{84}{95}$	$\frac{8}{8}$	$\frac{12}{12}$
Protozoa	4	5	$\frac{1}{1}$	$\frac{3}{3}$	$\frac{3}{3}$
Rhizopoda	23	73	...	$\frac{23}{73}$	$\frac{17}{17}$
Cœlenterata	6	7	$\frac{1}{1}$	$\frac{6}{6}$	$\frac{6}{6}$
Echinodermata	13	18	...	$\frac{13}{18}$	$\frac{13}{18}$
Annelida	8	14	$\frac{1}{1}$	$\frac{8}{13}$	$\frac{7}{9}$
Cirripedia	2	11	...	$\frac{2}{11}$	$\frac{2}{11}$
Entomostraca	33	148	...	$\frac{33}{148}$	$\frac{33}{134}$
Brachyura	5	5	...	$\frac{5}{5}$	$\frac{4}{4}$
Anomura	1	1	...	$\frac{1}{1}$	$\frac{1}{1}$
Polyzoa	9	23	...	$\frac{9}{23}$	$\frac{8}{11}$
Brachiopoda	3	3	...	$\frac{3}{3}$	$\frac{2}{2}$
Monomyaria	4	12	...	$\frac{4}{12}$	$\frac{4}{12}$
Dimyaria	57	172	$\frac{3}{3}$	$\frac{54}{169}$	$\frac{47}{145}$
Gasteropoda	82	302	$\frac{20}{97}$	$\frac{67}{205}$	$\frac{77}{266}$
Pisces	11	14	$\frac{10}{12}$	$\frac{2}{2}$	$\frac{12}{12}$
Aves	27	37	$\frac{31}{36}$	$\frac{1}{1}$	$\frac{32}{35}$
Mammalia	51	130	$\frac{51}{114}$	$\frac{10}{16}$	$\frac{10}{10}$
	410	1078	$\frac{172}{354}$	$\frac{240}{724}$	$\frac{284}{803}$

TABLE CXVI.—*Organic Remains of the Post-Pliocene Deposits.*

(See Plate XXXIIa.)

PLANTÆ. Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Arctostaphylos	1	1	...	1
Æsculus	1	1	...	1
Alnus	1	1	...	1
Arundo	1	1	...	1
Andromeda	1	1	...	1
Betula	2	2	...	2
Boletus	1	1	...	1
Brassica	1	1	...	1
Brachythecium	1	1	...	1
Callithamnion	1	...	1	...
Carex	1	1	...	1
Ceratophyllum	1	1	...	...
Chara	3	3	...	3

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Corallina	1	...	1	...
Climacium	1	1	...	..
Cosmarium	1	1	...	1
Corylus	1	1	...	...
Cratægus	2	2	...	...
Eleocharis	1	1	...	...
Erica	3	3	...	...
Equisetum	2	2	...	...
Eriophorum	1	1	...	...
Fagus	1	1	...	...
Ficus	1	1	...	...
Fraxinus	1	1	...	...
Galium	1	1	...	...
Hydrodyction	1	1	...	...
Hippuris	1	1	...	...

[1] Allowance must be made for the accuracy of this column. It is a very close approximation.

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Hypnum . .	10	10	...	...
Halydrys .	1	...	1	...
Ilex . .	1	1	...	...
Isothecum .	1	1	...	...
Iris . . .	1	1	...	...
Juncus . .	...	...	...	...
Juniperus .	1	1	...	...
Larix . .	1	1	...	...
Leskea . .	1	1	...	...
Melobesia .	2	...	2	...
Menyanthes .	1	1	...	...
Myrica . .	1	1	...	...
Myriophyllum	1	1	...	...
Narthecium .	1	1	...	...
Nomalia . .	1	1	...	...
Nullipora .	2	...	2	...
Nuphar . .	1	1	...	...
Nymphæa .	1	1	...	...
Osmunda .	1	1	...	..
Pendicularis .	1	1	...	...
Pinus . .	5	5	...	...
Potamogeton .	1	1	...	...
Pteris . .	2	2	...	...
Polyporus .	3	3	...	...
Polytrichum .	1	1	...	...
Pogonatum .	1	1	...	...
Prunus . .	2	2	...	...
Pyrus . .	2	2	...	...
Ranunculus .	1	1	...	...
Raconitrum .	1	1	...	...
Salix . .	5	5	...	...
Scirpus . .	2	2	...	...
Schœnus . .	1	1	...	...
Scutellaria .	1	1	...	...
Sphagnum .	2	2	...	...
Strobilites .	1	1	..	...
Taxus . .	1	1	...	...
Taxoxylon .	1	1	...	...
Typha . .	1	1	...	...
Ulmus . .	1	1	...	...
Ulex . .	1	1	...	...
Vaccinium .	1	1	...	...
Zostera . .	1	...	1	...
71	103	95	8	15

PROTOZOA.

SPONGIA.

Cliona . . .	1	...	1	1
Geodia: . . .	1	...	1	1
Halichondria .	1	...	1	1
Spongilla .	2	2	...	2
4	5	2	3	5

RHIZOPODA.

FORAMINIFERA.

Biloculina .	1	...	1	1
Bulimina .	4	...	4	1
Cassidulina .	1	...	1	1
Cornuspira .	1	...	1	1
Cristellaria .	1	...	1	1
Dentalina .	1	...	1	...
Discorbina .	3	...	3	2
Globigerina .	1	...	1	1
Lagena . .	15	...	15	8
Nodosaria .	5	...	5	2
Nonionina .	5	...	5	...
Planorbulina .	1	...	1	...
Polymorphina .	5	...	5	4
Polystomella .	4	...	4	3
Quinqueloculina	8	...	8	6
Robulina .	1	...	1	1
Rosalina . .	1	...	1	1
Trochanima .	2	...	2	...
Rotalia . .	3	...	3	...
Textularia .	3	...	3	...
Triloculina .	2	...	2	2
Truncatulina .	3	...	3	1
Vaginulina .	2	...	2	1
23	73		73	37

HYDROZOA AND ACTINOZOA.

Caryophyllia .	1	1	...	...
Endendrium .	1	...	1	1
Jania . .	1	...	1	1
Sertularia .	2	...	2	...
Millepora .	1	...	1	...
Sphænotrochus	1	..	1	1
6	7	1	6	3

ECHINODERMATA.

Amphidetus .	1	...	1	1
Echinocyamus	1	...	1	1
Echinus . .	4	...	4	4
Hoplaster . .	1	...	1	1
Ophiura . .	2	...	2	2

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Ophiocoma .	2	...	2	2
Ophiolepis .	1	...	1	1
Ophiothrix .	1	...	1	1
Psolus . .	1	...	1	1
Spatangus .	1	...	1	1
Sipunculus .	1	...	1	1
Toxopneustes .	1	...	1	1
Uraster . .	1	...	1	1
13	18		18	18
ANNELIDA.				
Filigrana .	1	1	...	..
Hæmopsis .	1	...	1	1
Limnorea .	1	1	...	1
Sabellaria .	1	...	1	1
Pectinaria .	1	...	1	1
Serpula . .	2	...	2	1
Spirorbis .	4	...	4	2
Vermilia .	3	...	3	2
8	14	2	12	9
CRUSTACEA.				
CIRRHIPEDIA.				
Balanus . .	10	...	10	9
Verruca . .	1	...	1	1
2	11	...	11	10
ENTOMOSTRACA				
Aglaia . .	1	...	1	...
Alona . .	3	...	3	3
Asterope . .	1	...	1	1
Argillæcia .	1	...	1	1
Bairdia . .	2	...	2	1
Bosquetia .	1	...	1	...
Bythocythere .	3	...	3	2
Candona . .	5	...	5	5
Camptoceras .	1	...	1	1
Cypris . .	10	...	10	8
Cypridopsis .	2	...	2	2
Chrydorus .	1	...	1	1
Daphnia .	1	...	1	1
Cythere . .	46	...	46	38
Cytheridea .	8	...	8	7
Cythereis .	1	...	1	...
Cytherura .	21	...	21	18
Cytheropteron .	6	...	6	6

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Cytheridus .	2	...	2	2
Darwinella .	1	...	1	1
Encythere .	1	...	1	1
Krithe . .	2	...	2	...
Limnicythere .	4	...	4	3
Loxoconcha .	6	...	6	6
Lymnoria .	1	...	1	1
Paradoxostoma	7	...	7	5
Polycope . .	1	...	1	1
Paracypris .	1	...	1	1
Pontocypris .	3	...	3	3
Potamocypris .	1	...	1	1
Pseudocythere	1	...	1	1
Sclerochilus .	1	...	1	1
Xestoleberis .	2	...	2	2
33	148		148	124
BRACHYURA.				
Cancer . .	1	...	1	...
Carcinas . .	1	...	1	1
Ebalia . .	1	...	1	1
Palinurus .	1	...	1	1
Galathea .	1	...	1	1
5	5		5	4
ANOMURA.				
Pagurus . .	1	...	1	1
MOLLUSCA.				
Division—MOLLUSCOIDA.				
Class – POLYZOA.				
Crisia . . .	2	...	2	2
Cellepora .	1	...	1	1
Discoporella .	2	...	2	1
Hippothoa .	2	...	2	...
Idmonea . .	1	...	1	...
Lepralia . .	7	...	7	3
Scrupocellaria .	1	...	1	...
Tubulipora .	6	...	6	4
Membranipora	1	...	1	...
9	23		23	11
BRACHIOPODA.				
Argiope . .	1	...	1	1

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Rhynchonella	1	...	1	1
Terebratulina	1	...	1	1
3	3		3	3
PELECYPODA.				
Monomyaria.				
Anomia	4	...	4	4
Lima	1	...	1	1
Ostrea	1	...	1	1
Pecten	6	...	6	6
4	12		12	12
Dimyaria.				
Abra	1	...	1	...
Anodonta	1	1	...	1
Anatina	1	...	1	...
Arca	2	...	2	2
Artemis	2	...	2	2
Astarte	10	...	10	9
Cardita	3	...	3	1
Cardium	12	...	12	12
Corbula	4	...	4	4
Crenella	2	...	2	2
Cryptodon	4	...	4	3
Cyamium	1	...	1	1
Cyprina	3	...	3	1
Cyrena	1	...	1	1
Cyrtodaria	1	...	1	...
Cytherea	3	...	3	2
Diplodonta	1	...	1	1
Donax	3	...	3	3
Erycinella	1	...	1	...
Gastrana	1	...	1	1
Glycimeris	1	...	1	...
Kellia	1	...	1	1
Lasæa	2	...	2	1
Leda	14	...	14	10
Lepton	1	...	1	1
Limopsis	1	...	1	1
Loripes	1	...	1	1
Lucina	3	...	3	3
Lucinopsis	1	...	1	1
Lutraria	3	...	3	3
Mactra	6	...	6	6
Modiola	2	...	2	2
Montacuta	2	...	2	2
Modiolaria	3	...	3	2
Mytilus	3	...	3	3
Mya	2	...	2	2
Nucula	7	...	7	4
Panopæa	1	...	1	1
Pectunculus	1	...	1	1
Pholas	3	...	3	3
Pisidium	4	...	4	4
Psammobia	2	...	2	2
Saxicava	2	...	2	2
Scrobicularia	2	...	2	2
Siliquaria	1	...	1	...
Solecurtus	2	...	2	2
Solen	4	...	4	4
Sphænia	1	...	1	1
Sphærium	2	2	...	2
Syndosmya	1	...	1	1
Tapes	5	...	5	5
Tellina	12	...	12	10
Teredo	1	...	1	1
Thracia	4	...	4	4
Unio	4	...	4	4
Venus	8	...	8	6
Woodia	2	...	2	1
57	172	3	169	145
GASTEROPODA.				
Achatina	1	1	...	1
Acicula	1	...	1	1
Aclis	1	...	1	1
Actæon	1	...	1	...
Adeorbis	2	...	2	2
Admete	1	...	1	1
Akera	1	...	1	1
Alvania	1	...	1	1
Ancylus	2	2	...	2
Aporrhais	1	...	1	1
Arion	1	1	...	1
Astyris	1	...	1	1
Balæa	1	...	1	1
Belgrandia	1	1	...	...
Buccinum	4	...	4	3
Bulimus	3	...	3	3
Bulla	1	...	1	1
Bythinia	2	2	...	2
Cæcum	1	...	1	1
Calyptræa	1	...	1	1
Carychium	2	2	...	1
Cemoria	1	...	1	1
Cerithium	3	...	3	2
Cerithopsis	2	...	2	2

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Chemnitzia	2	...	2	1
Chiton	8	...	8	6
Clausilia	5	5	...	5
Cochlipora	2	...	2	2
Columbella	1	...	1	1
Conovulus	1	...	1	1
Cyclostoma	1	1	...	1
Cyclostrema	2	...	2	2
Cylichna	3	...	3	3
Cypræa	1	...	1	1
Defrancia	3	...	3	3
Emarginula	1	...	1	1
Eulima	2	...	2	2
Elimella	1	...	1	...
Fissurella	1	...	1	1
Fusus	8	...	8	5
Helix	24	24	...	22
Helicon	2	...	2	2
Homalogyra	1	...	1	1
Hydrobia	3	3	...	3
Lachesis	1	...	1	1
Lacuna	6	...	6	6
Lepeta	1	...	1	1
Limax	2	2	...	2
Limnæa	5	5	...	5
Littorina	8	...	8	8
Margarita	3	...	3	3
Mesalia	1	...	1	1
Murex	1	...	1	1
Nassa	9	...	9	5
Natica	13	...	13	10
Nematurella	1	...	1	...
Neritina	1	...	1	1
Odostomia	10	...	10	10
Paludina	8	8	...	6
Patella	1	...	1	1
Phasianella	1	...	1	1
Physa	2	2	...	2
Planorbis	12	12	...	10
Pleurotomaria	12	...	12	5
Pupa	6	6	...	4
Purpura	3	...	3	2
Ringicula	1	...	1	...
Rissoa	18	...	18	16
Scalaria	5	...	5	5
Scaphander	1	...	1	1
Skenia	1	...	1	1
Succinea	4	4	...	4
Tectura	2	...	2	2
Trichotropis	2	...	2	2
Trochus	11	...	11	10
Trophon	15	...	15	19
Turritella	4	...	4	4
Utriculus	5	...	5	5
Valvata	1	1	...	1
Velutina	2	...	2	2
Vertigo	6	6	...	6
Zonites	9	9	...	9
82	302	97	205	266

Class—CEPHALOPODA.

None.

Class—PISCES.

Acipenser	2	1	1	2
Barbus	1	1	...	1
Esox	1	1	...	1
Gadus	1	1	...	1
Labrus	1	1	...	1
Leuciscus	3	3	...	3
Perca	1	1	...	1
Platessa	1	1	...	1
Platax	1	1	...	...
Raia	1	...	1	...
Tinca	1	1	...	1
11	14	12	2	12

Class—AVES.

Alauda	1	1	...	3
Aquila	1	1	...	2
Alca	1	...	1	1
Anas	2	2	...	7
Anser	4	4	...	5
Ardea	1	1	...	...
Buteo	1	1	...	5
Colymbus	1	1	...	3
Columba	2	2	...	3
Corvus	2	2	...	5
Cygnus	4	4	...	1
Fratercula	1	...	1	1
Fulica	1	1	...	1
Grus	1	1	1	1
Haliaetus	1	1	...	1
Lagopus	1	1	...	2
Larus	1	1	1	9
Oidemia	1	1	..	3
Otis	1	1	...	...
Pelicanus	2	...	2	...
Perdix	1	1	...	2
Phalacrocorax	1	...	1	...

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Podiceps	1	1	...	5
Sula	1	...	1	1
Somatoria	1	1	...	2
Scolopax	1	1	...	5
Uria	1	...	1	1
27	37	30	9	69

CLASS—MAMMALIA.

LAND AND FRESH-WATER.

Alces	1	1	...	...
Arvicola	10	10	...	7
Asinus	2	1	...	...
Bison	2	2	...	...
Bos	4	4	...	...
Canis	5	5	...	4
Castor	2	2	...	2
Capra	3	3	...	3
Caprovis	1	1	...	...
Cervus	15	15	...	3
Cricetus	1	1	...	1
Elephas	4	4	...	...
Equus	5	5	..	1
Felis	8	8	...	2
Gulo	1	1	...	1
Hippopotamus	1	1	...	...
Hyæna	2	2	...	...
Lagomys	1	1	...	...
Lemnus	3	3	...	2
Lepus	4	4	...	2
Lutra	1	1	...	1
Martes	2	2	...	2
Machairodus	3	3	...	...
Mastodon	1	1	...	...
Megaceros (cervus)	1	1	...	...
Meles	1	1	...	1
Mus	3	3	...	3
Mustella	3	3	...	3
Myogale	1	1	...	1
Ovibos	1	1	...	..
Rhinoceros	3	3	...	...
Rhinolophus	1	1	...	1
Sorex	4	4	...	4
Sciurus	1	1	...	1
Spermophilus	1	1	...	...
Sus	1	1	...	1
Talpa	1	1	...	1
Trogontherium	1	1	...	...
Ursus	6	6	...	...
Vespertilio	1	1	...	1
Vulpes	1	1	...	1
41	113	112		49

MARINE.

Balæna	2	...	2	...
Balænoptera	1	...	1	1
Delphinus	2	...	2	2
Halitherium	1	...	1	...
Monodon	1	...	1	1
Palæcetus	1	...	1	...
Phocæna	2	...	1	1
Physeter	1	...	1	1
Phoca	5	...	5	4
Trichæchus	1	...	1	...
10	17		16	10
51	130	112	16	59

(Including the Land and Fresh-water Genera.)

CORRIGENDA.

The Student is requested to make the following corrections as to the number of species in the earlier sheets with the pen. They are necessitated by progress made during the passing of the work through press.

Page 35, line 13 from top, *for* 32 *read* 31 species.
„ 39, „ 11 from top, *for* 103 *read* 110 species.
„ 39, „ 6 from foot, *for* 9 *read* 12 species.
„ 39, „ 11 from foot, *read* "5 genera, Theca, Cyrtotheca, Pterotheca, Stenotheca, and Conularia, represented by 16 species."
„ 40, „ 13 from top, *for* 61 genera and 182 species *read* 68 genera and 185 species.
„ 40, „ 14 from top, *for* 11 *read* 12 genera.
„ 40, „ 27 from top, *after* "flags" *add* "except one Heteropod (Bell. Cambr.) in the Middle Lingula.
„ 49, table v., *for* Brachiopoda $\frac{3}{5}$ *read* $\frac{3}{5}$.
„ 51, „ vi., *for* Crustacea $\frac{8}{10}$ *read* $\frac{8}{11}$.
„ 52, line 1 from foot, *for* 62 genera and 149 species *read* 60 genera and 147 species.
„ 54, „ 34 from top, *read* "The whole Tremadoc fauna consists of 51 genera and 93 species. The Arenig fauna includes 60 genera and 147 species. The succeeding Llandeilo has yielded 175 species."
„ 57, „ 2 from top, *read* "68 genera and 185 species."
„ 58, „ 24 from top, *for* 150 *read* 147 species.
„ 65, „ 9 from foot, *read* "genera (60) and species (147)."
„ 65, „ 3 from foot, *read* "48 genera and 131 species."
„ 66, „ 8 from top, *read* "131 species."
„ 73, „ 20 from foot, *for* 42 *read* 40 species.
„ 74, last line, *for* 150 *read* 147 species.
„ 85, line 12 from foot, *for* 16 *read* 15 species.
„ 87, „ 21 from top, *for* 110 *read* 67 species.
„ 95, „ 15 from top, *for* 240 *read* 204 species.

ERRATA.

„ 63, line 20 from top, *for* Scaafel *read* Scafell.
„ 80, „ 10 from top, *for* Tredadium *read* Tetradium.
„ 125, „ 32 from top, *for* 7 *read* 9 species.
„ 173, „ 19 from top, *for* Woodsbay *read* Woodabay.
„ 304, „ 16 from top, *for* Ostracacanthus *read* Ostracanthus.
„ 309, „ 15 from foot, *for* Acanthoclodia *read* Acanthocladia.
„ 321, „ 12 from top, *for* Trochamina *read* Trochammina.
„ 347, „ 8 from top, *for* Stegonolepis *read* Stagonolepis.
„ 589, „ 26 from top, *for* Clypeina *read* Clypenia.
„ 591, „ 11 from foot, *for* Pachyma *read* Pachymya.
„ 593, „ 20 from foot, *for* Ancycloceras *read* Ancyloceras.
„ 594, „ 3 from top, *for* Dephanophorus *read* Drepanephorus.
„ 611, „ 12 from top, *for* Bankinia *read* Bauhinia.
„ 633, „ 19 from foot, *for* Rhymatodes *read* Phymatodes.
„ 634, „ 1, *for* Iarteria *read* Iriartea.
„ 644, „ 1, *for* Agrillorius *read* Argillorius.
„ 687, „ 20 from top, *for* Pendicularis *read* Pedicularis.
Plate xii., *for* Prestrichia *read* Prestwichia.
„ xxiii. C, *for* Plexuosi *read* Flexuosi.

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TABLE CXV.—*Numerical Distribution of the Post-Pliocene (Pleistocene or Quaternary) Deposits.*

Classes.	Genera.	Species.	Land and Fresh-water.	Marine.	Living British.[1]
Plantæ	71	103	64/65	6/38	12/15
Protozoa	4	5	1/5	4/5	1/5
Rhizopoda	23	73	...	23/73	17/17
Cœlenterata	6	7	1/7	6/6	2/2
Echinodermata	13	18	...	13/18	13/13
Annelida	8	14	2/14	6/14	1/1
Cirripedia	2	11	...	2/11	1/5
Entomostraca	33	148	...	33/148	9/124
Brachyura	5	5	...	5/5	4/4
Anomura	1	1	...	1/1	1/1
Polyzoa	9	23	...	9/23	1/1
Brachiopoda	3	3	...	3/3	3/3
Monomyaria	4	12	...	4/12	4/4
Dimyaria	57	172	2/172	57/172	1/1
Gasteropoda	82	302	20/97	62/205	1/1
Pisces	11	14	10/14	9/9	1/1
Aves	27	37	28/30	9/9	23/23
Mammalia	51	130	51/114	10/16	20/20
	410	1078	173/854	240/724	284/303

TABLE CXVI.—*Organic Remains of the Post-Pliocene Deposits.*

(See Plate XXXII*a*.)

PLANTÆ.

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Arctostaphylos	1	1	...	1
Æsculus	1	1	...	1
Alnus	1	1	...	1
Arundo	1	1	...	1
Andromeda	1	1	...	1
Betula	2	2	...	2
Boletus	1	1	...	1
Brassica	1	1	...	1
Brachythecium	1	1	...	1
Callithamnion	1	...	1	...
Carex	1	1	...	1
Ceratophyllum	1	1	...	...
Chara	3	3	...	3
Corallina	1	...	1	...
Climacium	1	1	...	..
Cosmarium	1	1	...	1
Corylus	1	1	...	...
Cratægus	2	2	...	...
Eleocharis	1	1	...	...
Erica	3	3	...	...
Equisetum	2	2	...	...
Eriophorum	1	1	...	...
Fagus	1	1	...	...
Ficus	1	1	...	...
Fraxinus	1	1	...	...
Galium	1	1	...	...
Hydrodyction	1	1	...	...
Hippuris	1	1	...	...

[1] Allowance must be made for the accuracy of this column. It is a very close approximation.

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Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Podiceps . .	1	1	...	5
Sula . .	1	...	1	1
Somatoria .	1	1	...	2
Scolopax . .	1	1	...	5
Uria . .	1	...	1	1
—	—	—	—	—
27	37	30	9	69

CLASS—MAMMALIA.

LAND AND FRESH-WATER.

Alces . .	1	1	...	...
Arvicola . .	10	10	...	7
Asinus . .	2	1	...	...
Bison . .	2	2	...	...
Bos . . .	4	4	...	...
Canis . .	5	5	...	4
Castor . .	2	2	...	2
Capra . .	3	3	...	3
Caprovis . .	1	1	...	...
Cervus . .	15	15	...	3
Cricetus . .	1	1	...	1
Elephas . .	4	4	...	...
Equus . .	5	5	..	1
Felis . .	8	8	...	2
Gulo . .	1	1	...	1
Hippopotamus	1	1	...	...
Hyæna . .	2	2	...	...
Lagomys . .	1	1	...	...
Lemnus . .	3	3	...	2
Lepus . .	4	4	...	2
Lutra . .	1	1	...	1
Martes . .	2	2	...	2
Machairodus .	3	3	...	...
Mastodon .	1	1	...	...
Megaceros (cervus)	1	1	...	...
Meles . .	1	1	...	1
Mus . .	3	3	...	3
Mustella . .	3	3	...	3
Myogale . .	1	1	...	1
Ovibos . .	1	1	...	..
Rhinoceros .	3	3	...	...
Rhinolophus .	1	1	...	1
Sorex . .	4	4	...	4
Sciurus . .	1	1	...	1
Spermophilus .	1	1	...	...
Sus . . .	1	1	...	1
Talpa . .	1	1	...	1
Trogontherium	1	1	...	...
Ursus . .	6	6	...	...
Vespertilio .	1	1	...	1
Vulpes . .	1	1	...	1
—	—	—		—
41	113	112		49

MARINE.

Balæna . .	2	...	2	...
Balænoptera .	1	...	1	1
Delphinus .	2	...	2	2
Halitherium .	1	...	1	...
Monodon .	1	...	1	1
Palæcetus .	1	...	1	...
Phocæna .	2	...	1	1
Physeter . .	1	...	1	1
Phoca . .	5	...	5	4
Trichæchus .	1	...	1	...
—	—		—	—
10	17.		16	10
—				
51	130	112	16	59

(Including the Land and Fresh-water Genera.)

TABLE CXVI.—(*Continued.*)

Genera.	No. of Species.	Land and Fresh-water.	Marine.	Recent or Living.
Chemnitzia	2	...	2	1
Chiton	8	...	8	6
Clausilia	5	5	...	5
Cochlipora	2	...	2	2
Columbella	1	...	1	1
Convulus	1	...	1	1
Cyclostoma	1	1	...	1
Cyclostrema	2	...	2	2
Cylichna	3	...	3	3
Cypræa	1	...	1	1
Defrancia	3	...	3	3
Emarginula	1	...	1	1
Eulima	2	...	2	2
Elimella	1	...	1	...
Fissurella	1	...	1	1
Fusus	8	...	8	5
Helix	24	24	...	22
Helicon	2	...	2	2
Homalogyra	1	...	1	1
Hydrobia	3	3	...	3
Lachesis	1	...	1	1
Lacuna	6	...	6	6
Lepeta	1	...	1	1
Limax	2	2	...	2
Limnæa	5	5	...	5
Littorina	8	...	8	8
Margarita	3	...	3	3
Mesalia	1	...	1	1
Murex	1	...	1	1
Nassa	9	...	9	5
Natica	13	...	13	10
Nematurella	1	...	1	...
Neritina	1	...	1	1
Odostomia	10	...	10	10
Paludina	8	8	...	6
Patella	1	...	1	1
Phasianella	1	...	1	1
Physa	2	2	...	2
Planorbis	12	12	...	10
Pleurotomaria	12	...	12	5
Pupa	6	6	...	4
Purpura	3	...	3	2
Ringicula	1	...	1	...
Rissoa	18	...	18	16
Scalaria	5	...	5	5
Scaphander	1	...	1	1
Skenia	1	...	1	1
Succinea	4	4	...	4
Tectura	2	...	2	2
Trichotropis	2	...	2	2
Trochus	11	...	11	10
Trophon	15	...	15	19
Turritella	4	...	4	4
Utriculus	5	...	5	5
Valvata	1	1	...	1
Velutina	2	...	2	2
Vertigo	6	6	...	6
Zonites	9	9	...	9
82	302	97	205	266

Class—CEPHALOPODA.

None.

Class—PISCES.

Acipenser	2	1	1	2
Barbus	1	1	...	1
Esox	1	1	...	1
Gadus	1	1	...	1
Labrus	1	1	...	1
Leuciscus	3	3	...	3
Perca	1	1	...	1
Platessa	1	1	...	1
Platax	1	1	...	...
Raia	1	...	1	...
Tinca	1	1	...	1
11	14	12	2	12

Class—AVES.

Alauda	1	1	...	3
Aquila	1	1	...	2
Alca	1	...	1	1
Anas	2	2	...	7
Anser	4	4	...	5
Ardea	1	1	...	...
Buteo	1	1	...	5
Colymbus	1	1	...	3
Columba	2	2	...	3
Corvus	2	2	...	5
Cygnus	4	4	...	1
Fratercula	1	...	1	1
Fulica	1	1	...	1
Grus	1	1	1	1
Haliaetus	1	1	...	1
Lagopus	1	1	...	2
Larus	1	1	1	9
Oidemia	1	1	...	3
Otis	1	1	...	...
Pelicanus	2	...	2	...
Perdix	1	1	...	2
Phalacrocorax	1	...	1	...

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